U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

AD-A031 211

FEASIBILITY OF MEETING THE ENERGY NEEDS OF ARMY BASES WITH SELF-GENERATED FUELS DERIVED FROM SOLAR ENERGY PLANTATIONS (APPENDICES D, E, F, G, AND H)

InterTechnology Corporation, Warrenton, Virginia

July 1976

303088

AD A031211

ITC NO. 260675

FINAL REPORT

APPENDICES D, E, F, G, AND H

FEASIBILITY OF MEETING THE ENERGY NEEDS OF ARMY BASES WITH SELF-GENERATED FUELS DERIVED FROM SOLAR ENERGY PLANTATIONS

SPONSORED BY

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

ARPA ORDER NUMBER: 2630

PROGRAM CODE NUMBER: 4F10

CONTRACT NUMBER: DACA 23-74-C-0009

EFFECTIVE DATE OF CONTRACT: FEBRUARY 28, 1974

CONTRACT EXPIRATION DATE: APRIL 30, 1975

AMOUNT OF CONTRACT: $72,814.00

PRINCIPAL INVESTIGATOR: Dr. George C. Szego

PHONE: 703-347-7900

PROGRAM MANAGER: Dr. Clinton C. Kemp

PHONE: 703-347-7900

CONTRACTOR:

INTERTECHNOLOGY CORPORATION

WARRENTON, VIRGINIA 22186

FORM APPROVED, BUDGET BUREAU- NO. 22 - R 0293

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) FEASIBILITY OF MEETING THE ENERGY NEEDS OF ARMY BASES WITH SELF-GENERATED FUELS DERIVED FROM SOLAR ENERGY PLANTATIONS (APPENDICES D, E, F, G, AND H)		5. TYPE OF REPORT & PERIOD COVERED FINAL
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s)		8. CONTRACT OR GRANT NUMBER(s) DACA 23-74-C-0009
9. PERFORMING ORGANIZATION NAME AND ADDRESS Intertechnology Corporation Warrenton, VA 22186		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS DEFENSE ADVANCED RESEARCH PROJECTS AGENCY 1400 Wilson Blvd Arlington, VA 22209		12. REPORT DATE July 1976
		13. NUMBER OF PAGES 313
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) CONSTRUCTION ENGINEERING RESEARCH LABORATORY P. O. Box 4005 Champaign, IL 61820		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Copies are obtainable from National Technical Information Service
Springfield, VA 22151

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

energy plantation
fuels
plant materials

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This project thoroughly investigated the possibility of collecting and storing solar radiation in plants especially grown for their fuel value as a source of fuel on U. S. Army bases.

The study investigated the merit of producing this fuel at energy plantations at or near the bases. The fuel would be used for directly fired steam generators, hot water heaters, space heaters, and cooking.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Block 20 continued.

The research examined the major characteristics of energy plantations; analyzed plant-matter production rates from deciduous plants; and examined fuel consumption in stationary facilities at major troop training centers. The possibilities and requirements of energy plantations at Fort Benning, Fort Leonard Wood, and at Army bases in general were detailed.

It was concluded that energy plantations could be feasible at approximately 15 large Army bases and that the cost of solid fuel produced from them would be approximately $1/1 million Btu; the cost of synthetic natural gas produced from plants was determined to be approximately $3.10 to $4.20/1000 standard cu ft.

Besides being a perpetually renewable fuel source, it was found that energy plantations could provide independence from other fuel sources, reduction in future environmental problems caused by present fuels, and will productively use land not now in active use.

TABLE OF CONTENTS

TABLE OF CONTENTS

APPENDIX D

PROCESS ENGINEERING OF ANAEROBIC DIGESTION FOR PRODUCING SNG FROM PLANT MATERIAL

TABLE OF CONTENTS
(continued)

TABLE OF CONTENTS
(continued)

I. BASICS OF ANAEROBIC DIGESTION - A REVIEW

As an introduction to the process engineering involved in producing synthetic natural gas from plant material, this section is a brief description and review of anaerobic digestion. For a more detailed description, reviews 1, 2, and 3 cited in the reference list at the end of this appendix will be found helpful.

Essential to an understanding of a process involving anaerobic digestion is an appreciation of the requirements for the system environment for the microorganism population. These requirements and other operational considerations[4,5] are discussed in the second part of this section.

I.A. General Description. Anaerobic digestion generally refers to the naturally occurring process of biologically induced degradation of organic materials in the absence of elemental oxygen. Aerobic digestion, another widely prevalent biological process which degrades organic material, proceeds only in the presence of elemental oxygen. The microorganisms involved in anaerobic digestion are different from those which take part in aerobic digestion. The products of anaerobic digestion are different from those produced by aerobic digestion.

The microorganisms in anaerobic and aerobic systems derive the energy they require for reproducing themselves and for digesting organic material by oxidizing chemically bound carbon to carbon dioxide and, in the case of aerobic digestion, also hydrogen and certain other elements in organic materials to their highest states of oxidation (water in the case of hydrogen). In aerobic digestion, the oxygen required for the oxidation reactions and for microorganism reproduction is derived primarily from elemental oxygen in the air or from some other source, and to a lesser extent from oxygen

in the organic materials being digested. Aerobic digestion is noticably exothermic.

In anaerobic digestion, the oxygen required by the microorganisms is supplied by oxygen which is chemically bound in the organic material being digested. Thus, anaerobic digestion involves simultaneous chemical oxidation and reduction of carbon and certain other elements, including hydrogen, in the organic material being digested. The ultimate products of anaerobic digestion are therefore a mixture of fully oxidized carbon, that is carbon dioxide, and other compounds in which at least some of the carbon, hydrogen and certain other elements are in a lower state of oxidation than they were in the organic material prior to its digestion. Anaerobic microorganisms can exist and function, therefore, only in the presence of oxygenated organic compounds, and the degree to which they consume the organic material available to them probably depends on the ratio of oxygen to the other elements in the materials being digested. Anaerobic digestion is only very slightly exothermic.

Anaerobic microorganisms are surprisingly adept at wresting oxygen from oxygenated materials. They will, for instance, reduce nitrogen in nitrates to elemental nitrogen and even to ammonia if there is a source of hydrogen chemically combined in an oxygenated compound available to them.

By suitably selecting the microorganisms for anaerobic digestion and also the organic material to be digested, the major products of the digestion can be carbon dioxide, methane and biological cell matter. Neither under these circumstances, nor any others in which anaerobic digestion occurs, are the chemical reactions involved easily analyzed by a stoichiometric approach because the overall biological process consists of a relatively large number of separate and sequential biochemical reactions in which a variety, often large, of microorganisms participate.

When methane is one of the products of anaerobic digestion produced in substantial yield, the entire biochemical process is generally considered to be divided into two phases. The first, called the acid-forming phase, involves breakdown of complex organic substrates into simple low-molecular-weight, water-soluble fatty acids -- such as acetic, propionic and butyric acids -- or to alcohols by means of enzymes associated with certain types of microorganisms. For the second phase, the simple fatty acids and alcohols are acted on by another set of bacteria which break these simple water-soluble organic materials into the final products, namely carbon dioxide and methane. New bacterial cell material is produced in parallel with the other activities of the phases. The basic conversion steps in the anaerobic fermentation are:

$$\begin{array}{c}\text{Complex Organic}\\ \text{Substrate}\end{array} \xrightarrow{\begin{array}{c}\text{Acid-forming}\\ \text{phase}\end{array}} \begin{array}{c}\text{Simple Organic}\\ \text{Acids}\\ \text{Alcohol}\\ \text{Bacterial Cells}\end{array} \xrightarrow{\begin{array}{c}\text{Methane-forming}\\ \text{phase}\end{array}} \begin{array}{l}CO_2\\ CH_4\\ \text{Bacterial Cells}\end{array}$$

In contrast to many other types of fermentations, methane generation by anaerobic digestion may be carried out with mixed cultures of microorganisms; sterile feed and pure culture inoculations are not required. Therefore, a variety of organic materials (such as that in plant material) can be digested simultaneously.

To start up a new anaerobic digestion system, the microorganism population can be started simply with seed sludge from another system. Other sources of microorganisms can be used, such as mud from the bottom of a deep pond. A certain amount of time is required for the microorganism population to increase to the proper operating level and, since many different kinds of bacteria can participate in the anaerobic digestion process, for the relative

numbers of the various kinds of bacteria required to adjust to the particular feed composition and other characteristics of the new system. These adjustments in microorganism population can take as long as several weeks because of the relatively slow growth rate of anaerobic bacteria, and of the methane-formers in particular.

For the anaerobic process to occur efficiently, the two general kinds of bacteria --the acid-formers and the methane-formers-- must be in proper balance. When such is the case, the rate of methane formation from the volatile acids will be equal to the rate of formation of the acids. However, the methane-forming bacteria are much more sensitive to environmental conditions (pH and temperature particularly) than the acid-formers. Thus, if the feed rate of digestible organic matter to the digester increases too rapidly, the rate of formation of acids is increased, but the methane-formers may not be able to increase their numbers fast enough to digest the increased amount of volatile acids. In this event the acids build up, the pH can become too acid for the methane-formers, and their population will decline sharply resulting in cessation of methane production and a so-called "stuck digester".

Like most other microorganisms, anaerobic bacteria flourish within two distinct temperature ranges of maximum acti ty. The low-temperature range which extends from about 80° to about 105° Fahrenheit, is called the mesophilic region of bacterial activity. The high-temperature range, called the thermophilic region, extends from about 120° to about 145° Fahrenheit. The species of anaerobic bacteria which dominate in each of these regions are different. There is controversy regarding the temperature dependence of bacterial activity both within the two regions and in one compared with the other. However, most experimental data generally indicate that bacterial activity is at least somewhat higher in the thermophilic temperature range than in the mesophilic.

For maximum activity and good growth and maintenance of the microorganism population, the digester feed must contain sufficient amounts of certain inorganic nutrients, such as fixed nitrogen and phosphorus, and other materials in small quantities. Sewage sludge sometimes contains sufficient amounts of these nutrients naturally; for industrial wastes in which the composition is more specific, these nutrients may have to be added to the digester feed for optimum operation. Certain of them will have to be added to a feed grown in an Energy Plantation.

An important parameter in the design and operation of an anaerobic digestion system is the so-called retention time of the solids within the system. For a continuously stirred tank-type digester, the retention time is equal to the digester slurry volume divided by the volumetric rate of withdrawal of slurry from the digester. The greater the retention time, the greater is the fraction of the digestible organic material in the feed which is digested.

There is a minimum retention time at which the digester can be operated continuously. This minimum is the so-called washout time. If the digester is operated at a retention time less than the washout time, the microorganisms cannot reproduce fast enough to replenish those which expire and those washed out of the system in the digester effluent. The washout time is a function of the particular microorganism population, composition of the feed and the level of nutrients available to the microorganisms, among other operating variables. Although the washout time cannot be predicted for a given system, it commonly ranges between four and seven days for anaerobic methane-forming microorganisms.

<u>I.B. Operational Considerations</u>. It has been noted already that the digester feed must contain adequate amounts of essential nutrients for the microorganisms.

If the microorganism culture is well maintained and the digester is operated at a retention time greater than the washout time, the rate of digestion will be steady and high, and the bacteria will reproduce themselves at a rate conducive to maintaining stable digester operation. The nutrient required in the greatest quantity by the bacteria is fixed nitrogen. It has been found experimentally in one study that the minimum amount of fixed nitrogen in the digester feed is such that the ratio of digestible carbon in the feed to the fixed nitrogen in the feed is about sixteen. Other investigators have found that the carbon-to-nitrogen ratio in steadily operated digesters can be as high as twenty, or even higher. The amount of nitrogen necessary is undoubtedly a function of the particular microorganism population and the composition of the feed.

The amount of phosphorous in the feed should be from one-eighth to one-fifth of the amount of nitrogen.

For proper digester operation, the pH of the slurry in the digester must be maintained within relatively narrow limits. The methane-forming bacteria are more sensitive to pH than are the acid-formers, and will tolerate a range in pH between about 6.2 and 7.8 but function best in the range from about 6.8 to 7.2.

Perhaps the most important principle that must be remembered for achieving stable, optimum operation of an anaerobic digester is that operating conditions must be kept constant and that operational changes, if deliberately induced, must be carried out slowly to allow time for the microorganism culture to adapt to the changed conditions. Thus, to achieve a high daily rate of loading of digestible organic material per cubic foot of digester, the loading must be built up gradually over a period possibly as long as thirty days or more, thereby allowing sufficient time for the microorganisms to

adapt to the changing feed rate. Also in line with this principle, the temperature must be kept steady within a range of only several degrees at the most.

The contents of the digester must be thoroughly mixed, both to assure a uniform temperature throughout the digester and to prevent zones of high volatile-acids concentration from developing -- particularly in a floating scum layer. Thorough circulation also enables the entire digester slurry volume to be utilized effectively and assures that the microorganisms have ready access to the materials they require.

For good control of the digester operation, a number of tests have been found to be essential. One of these is regular analysis of the digester effluent for its volatile-acids content. If the relative activity of the acid-formers and the methane-formers is getting out of balance, for instance, the volatile-acids content will show a rising trend before other indicators, such as a changed pH or diminution of the gas production rate, will indicate operational difficulty.

Much of the work concerned with digestion control has been directed at maintaining proper pH conditions. There is controversy in the literature about the interrelation between volatile acids and pH during digestion, and about the proper method for correcting an excess of volatile acids. According to one school of thought, the lowering of the pH induced by the increasing volatile-acid concentration is the factor which is toxic to the methane-forming bateria, and therefore,to protect the biological system, pH buffering material shculd be added to the digester. Lime is often used for this purpose.

The other view is that a volatile-acids concentration above a certain

level causes retardation of the methane-formers, independent of the pH. Th only remedy is to reduce the digester loading or to dilute the digester contents.

A more recent hypothesis is the theory of "salt toxicity", which holds that the relative effectiveness of various materials utilized for neutralization is a function of the cation portion of the materials. The work on which this theory is based indicates that calcium has the least toxicity of any of the alkali metals. The influence that any particular cation has on the digestion operation is affected greatly, however, by the other cations present.

Another useful measurement indicating the condition of the digester is the compositional analysis of the effluent gas. An increasing carbon dioxide content is a sure indication of an upset condition, as is a decreasing quantity of gas produced.

Other useful tests include total solids content, volatile-solids content and alkalinity of the digesting slurry.

This discussion of digester operation is not meant to be comprehensive; its purpose is rather to provide an introduction to some important concepts involved in operating an anaerobic digestion system. Because anaerobic digestion is not a precisely defined reaction and there are many different types of microorganisms and substrates involved, there is a certain amount of art involved in operating an anaerobic digester. Procedures which work for one system may not be so successful for another.

II. ANAEROBIC DIGESTION OF WOODY PLANT MATERIAL

II.A. Previous Experiments. Only a few experiments have apparently been made to study anaerobic digestion of woody plant material. Most of those that have, fall into one of two categories. The first is experiments to determine whether wood residues of the kind found in solid waste can be consumed by anaerobic digestion. The second has been concerned with rendering wood digestible by ruminant animals.

Until about fifteen years ago, there were few references in the literature about anaerobic digestion of wood, and such as there are, make vague assertions that wood, and particularly its lignin fraction, is biologically indigestible under anaerobic conditions. In the early 1960's, anaerobic digestion of wood was studied at the Federal Water Quality Administration, and attempts were even made to isolate or develop anaerobic microorganisms which would digest wood especially effectively. However, the work was not successful and was never published.[8]

Recent experiments on the anaerobic digestion of wood have been made as part of a program to study solid waste management.[9] The wood, white fir, was ground to a fine powder and included, along with sludge, in the feed to an anaerobic digester. The wood apparently underwent little, if any, biological reduction, but it did not have a toxic or other negative effect on the digestion of the other material either.

In the same program, as well as in other programs, shredded newspaper was included in the digester feed. This material appeared to digest to a certain extent, but the results cannot be applied directly to unprocessed wood since it is clear that the pulping and subsequent papermaking processes have drastically changed the chemical and physical properties of the original wood.

It is well known that cellulose in a more or less pure state digests readily under anaerobic conditions. The most comprehensive study of its digestion from a kinetic point of view was done recently as part of a program on solid waste management[10]. The material used for digestion in that work was a finely powdered kraft papermakers' pulp. It was, therefore, relatively pure cellulose. The powdered kraft is not, however, exactly like the material to be fed to the anaerobic digesters in the process proposed for making synthetic natural gas at Army training centers, but of the data available, those compiled for the powdered kraft are the most nearly applicable for the proposed SNG process.

In the powdered kraft digestion experiments, the microorganisms population was carefully maintained so that the results appear to be the best indication of the yield of methane and rate at which it would be produced from plant material grown in Energy Plantations. The data show that ninety-three percent of the available cellulose was digested with a retention time of fifteen days under mesophilic temperature conditions. The data also show that cellulose solubilization is the rate-limiting step in the overall digestion process.

The second category of previous experiments is concerned with rendering wood digestible by ruminant animals. In these experiments, wood was treated in various ways and then exposed to rumen fluid,which is biologically active. The rate at which the wood was digested by the fluid and the extent of the digestion were recorded. While these data may bear little relation to the rate of digestion and methane yield in the proposed process for producing synthetic natural gas, they are useful for indicating the relative digestibilities of various species and the effects of various pretreatments in promoting digestibility of woody material. A fact of particular importance is that softwoods are much more difficult to prepare as animal

feed and are much less digestible than are hardwoods. The data also constitute proof that woody plant material can be made digestible with suitable processes and conditions of pretreatment.

<u>II.B. The Ideal Species for Woody Feed Material</u>. From the work reported on converting woody plant material into feed for ruminants, it is clear that both the rate and the extent of digestion are species-dependent. An important question in the design of an Energy Plantation then becomes: what are the most appropriate species to grow in Energy Plantations as raw material for synthetic-natural-gas production? The feed material for the anaerobic digestion process can be chosen rather than simply accepted, as necessarily is the case where utilization of existing wood residues is the objective. The choice of feed material, however, may be constrained to some extent by the practicalities of growing it in the Energy Plantation.

However, since few previous experiments have been made on anaerobic digestion of woody plant material of any species, the literature is silent about how to choose the ideal Btu Bush for this purpose. Useful indications can be obtained from the data on preparation of animal feed. The ideal Btu Bush, from the viewpoint of gas production, must be ideal from the viewpoints of both the rate of digestion and the practically obtainable yield of methane.

Because of the lack of specific data, the ideal Btu Bush must be inferred from consideration of the rate and the degree to which various woody species are susceptible to chemical and biological attack. Information has been sought, therefore, on the decay and chemical degradation characteristics of various species. Of special interest is the relationship between the physical structure and chemical composition of woods, on the one hand, and the ease of their degradation, on the other.

From these considerations, the ideal woody Btu Bush should have the following general relative characteristics[11]:

- low lignin content,
- low fraction of insolubles in one percent caustic soda solution,
- high hemicellulose content,
- high pentosans content,
- high extractives content, and
- low ratio of modulus of rupture to work-to-maximum load.

The requirement on lignin content indicates that the ideal woody species is probably a hardwood rather than a softwood. Softwoods in general have a significantly higher lignin content than do hardwoods (thirty percent versus around twenty-three percent), and the lignin is of a distinctly different type which gives softwoods more decay resistance. Among various hardwoods, the lignin varies in composition so that the most degradable species must be found from data on decay resistance.

Hemicelluloses and pentosans are more easily degraded than molecularly highly oriented cellulose, such as alpha-cellulose. An easily degradable species should probably have, therefore, a relatively high proportion of hemicellulose and pentosans. In addition, pentosans (polymers of five-carbon sugars) yield slightly more gas per pound on a theoretical basis than cellulose and other polymers of six-carbon sugars (7.18 versus 7.02 standard cubic feet of methane per pound of dry material).

A low ratio of modulus of rupture to work-to-maximum load indicates that the cell walls in such woods have a high internal-surface accessibility,

and the wood should therefore be less resistant to chemical attack. A high ratio of cell-wall surface area to cell-wall thickness also would be a good indicator of the availability of the wood to microbial attack.

Another consideration is the type of extractives in the wood. Although a high proportion of extractives means that the wood contains a notable amount of material which may be readily accessible to the methane-forming organisms, the extractives must not be toxic to the microorganisms in the digester. Data on decay resistance may indicate whether or not this could be a problem with any particular species.

There do not appear to be any correlations useful for selecting plant species between the chemical resistance and specific gravity, water permeability, or alpha-cellulose content of the wood substance.

The potential digestibility of a particular species also depends on the age of the wood harvested and the time elapsed since it was harvested. Young wood (five years old or less) consists mostly of sapwood, and sapwood has a more open and amorphous cell structure than does heartwood. Sapwood in general has little or no resistance to decay, indicating that sapwood has a greater susceptibility to biological attack. The lignin in younger wood (sapwood) is also more accessible to chemical and microbial attack because it is found in parts of the cell-wall structure more accessible to the cytoplasm. Conversely, the lignin in older wood (heartwood) is less accessible to the cytoplasm.

After a woody plant has been cut and the wood ages and dries out, the lignin undergoes chemical changes which tend to make the whole woody structure more resistant to biological attack. Thus, it will be better to feed green, just-cut wood to the digestion process rather than old, seasoned wood. Since

water must be supplied to the process, it certainly is better to use green wood, with all of its moisture, in the process rather than to let the wood dry out first.

Although a wide variety of organic compounds can be reduced anaerobically to methane and carbon dioxide, the yield of gas depends on the compound's carbon content. Some of the materials found in woody plant matter produce methane more readily or in larger quantities than others. The potential yield of gas from a particular woody species therefore depends on its chemical composition.

A general formula has been proposed in the literature[12] for anaerobic conversion of complex organic materials to carbon dioxide and methane. The formula provides theoretical maximum-yield estimates because it makes no provision for:

- materials consumed in generating microorganisms to replace those lost for a variety of practical reasons;
- side reactions which may produce materials other than methane and carbon dioxide;
- failure to convert all the substrate material present into the final reaction products, namely carbon dioxide and methane; and
- recent experimental data, to be discussed in a subsequent section, indicating that the ratio between methane and carbon dioxide produced may be somewhat higher than the theoretical equations suggest.

The formula is shown in Table D-I. Also shown in the table are applications of the formula to anaerobically digestible materials found in, or produced from, plant material in substantial quantities. These compounds are acetic acid, cellulose (and other six-carbon sugar precursors), xylans (five-carbon

sugar compounds) and a representative protein and fatty acid. Another compound found in substantive quantity in wood is lignin. However, there is no evidence known which suggests that lignin is digestible under anaerobic conditions, although it is known to be digestible in an aerobic environment. Under these latter conditions, methane is not a product of digestion. Lignin therefore is assumed to be inert in the methane production process being considered here. Ash is inorganic and therefore is also inert.

The theoretical yield of methane from wood depends on its chemical composition. The total yield is comprised of the yields from the individual digestible compounds in the woody raw material. Although different species have different compositions, the most significant difference is between hardwoods and softwoods. The chemical composition of an "average" hardwood[13,14] is shown in Table D-II where the theoretical yield of methane from such a wood is shown to be 5.33 standard cubic feet of methane per pound of dry wood. The composition of an "average" softwood[13,14] and the theoretical methane yield from it are shown in Table D-III. Softwood has a lower theoretical yield, 4.88 standard cubic feet per dry pound of wood, than hardwood because it has fewer xylans and less total digestible material (and more indigestible lignin).

It should be noted that these yields do not allow for the necessary continuing production of bacterial cells which must inevitably occur while digestion is being carried out. Approximately ten percent of the carbon in the substrate is used for this purpose. The theoretical yields of methane shown in Tables D-II and D-III therefore overstate the maximum practical yields by at least ten percent.

Chemical composition, and hence also the theoretical methane production capacity, also varies between species within the hardwood and softwood classes.

Where the composition is known for a particular species, an estimate of the amount of methane which can theoretically be produced can be calculated from the generalized formula shown in Table D-I. However, the chemical composition of plant material produced by a particular species also varies quite markedly because of the effect of local factors at the site on which it is grown. The factors include influences of the soil, climate, water supply, nutrient availability and probably other matters. Only limited reliance can be placed therefore on the methane yield estimates shown in Tables D-II and D-III.

From the viewpoints of both rate of digestion and potential methane yield, the ideal Btu Bush for use as woody feed material for gas production by anaerobic biological digestion is a hardwood of a more reactive species as shown by data on composition, decay resistance, and digestion as animal feed. The woody feed material should be harvested while still young (less than five years old) and fed to the digester in the green state.

II.C. Pretreatment of Woody Material.

II.C.1. General. It is clear from experimental work reported in the literature on anaerobic digestion of wood and production of animal feed suitable for ruminants that some sort of pretreatment is necessary to make woody material susceptible to attack by the microorganisms involved. A variety of pretreatments is considered in the literature, primarily in connection with processes for making wood into a feed digestible by ruminants. Pretreatments considered include use of strong acid or alkali, exposure to sulfur dioxide or ammonia, chemical pulping, irradiation with high-energy electrons, steeping in steam or hot water, and grinding into fine particles. A review of these various methods has recently been published[15].

TABLE D-I

THEORETICAL YIELD OF METHANE FROM COMPLEX ORGANIC MATERIALS

General Formula:

$$C_n H_a O_b N_c + [n - \frac{a}{4} - \frac{b}{2} + \frac{7c}{4}] H_2O \longrightarrow [\frac{n}{2} - \frac{a}{8} + \frac{b}{4} - \frac{5c}{8}] CO_2 +$$

$$[\frac{n}{2} + \frac{a}{8} - \frac{b}{4} - \frac{3c}{8}] CH_4 + c\ NH_4HCO_3$$

Acetic Acid:

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

Yield of Methane = 6.32 SCF*per pound of acetic acid

Cellulose:

$$C_6(H_2O)_5 + H_2O \longrightarrow 3CO_2 + 3CH_4$$

Yield of Methane = 7.02 SCF*per pound of cellulose

Xylans:

$$C_5(H_2O)_4 + H_2O \longrightarrow 2.5\ CO_2 + 2.5\ CH_4$$

Yield of Methane = 7.18 SCF*per pound of xylan material

Protein (Hydroxyproline):

$$C_5H_9NO_3 + 3H_2O \longrightarrow 1.5\ CO_2 + 2.5\ CH_4 + NH_4HCO_3$$

Yield of Methane = 7.25 SCF*per pound of hydroxyproline

Fatty Acid (Linoleic Acid):

$$C_{18}H_{32}O_2 + 9H_2O \longrightarrow 5.5\ CO_2 + 12.5\ CH_4$$

Yield of Methane = 17.0 SCF*per pound of linoleic acid

SCF: Standard cubic feet of methane measured at one atmosphere and 60° Fahrenheit.

Although all these pretreatment methods appear to be helpful in some degree, the extent of their effect tends to be species-dependent, and they have various other advantages and disadvantages also. For a feasible, economic process for producing synthetic natural gas from woody material, steeping in steam or hot water combined with grinding appears to be the most suitable pretreatment method. This procedure offers the great advantage of avoiding the expense and problems of having to provide, use and dispose of pretreatment chemicals, possibly in substantial quantities.

Extensive steaming with or without subsequent grinding is being seriously considered by others for processing wood chips into a food for animals, and work has been done at several locations to study the process[16,17]. As a result, a few data have been produced which can be used as the basis for process calculations applicable to the purposes of this appendix for this process. Since various kinds of wood are represented in the available data, the data also serve to shed light on which woods are probably to be preferred for anaerobic digestion. For example, the data indicate that it is generally very difficult to promote anaerobic digestion of softwoods. Whereas among the hardwoods, the data for aspen, which has been extensively studied, indicate that it can be rendered susceptible to anaerobic biological attack. Moreover, the limited data available with respect to decay resistance and other evidences of reactivity of juvenile wood from various hardwood species (poplar and sycamore, for instance), suggest that the aspen data are representative of the effect of steaming and grinding young wood from other reactive deciduous species[18].

The digestibility estimates from the steaming and grinding studies reported in the literature were specifically made for determining biological digestion by rumen fluid, the purpose of the studies having been to estimate the digestibility of pretreated woody material in the alimentary tracts of

TABLE D-II

THEORETICAL YIELD OF METHANE FROM "AVERAGE" HARDWOOD

Chemical composition of an "average" bone-dry hardwood[13,14]:

	Percent by Weight
Hemicellulose, 5-carbon polysaccharides	20
Hemicellulose, 6-carbon polysaccharides	5
Cellulose	45
Lignin	23
Acetyl groups	6
Ash	1
	100

Theoretical yield of methane from anaerobically digestible materials:

	Standard Cubic Feet Per Pound of Bone-Dry Wood
Methane from 5-carbon polysaccharides	1.44
Methane from 6-carbon polysaccharides	0.35
Methane from cellulose	3.16
Methane from acetyl groups	0.38
	5.33

ruminants. These digestibility estimates are not necessarily translatable therefore into the kind of digestibility required for methane production by anaerobic digestion of plant material. However, no other data have been found on the effect of pretreatment procedures on juvenile woody material for this purpose. The rumen digestibility estimates are the only available indications of the effect steaming and grinding may have on the extent to which, and rate at which, pretreated wood is attacked by biological organisms. Consequently, they are the only data available for estimating pretreatment conditions which can be expected to promote the desired biological digestibility of juvenile woody materials pertinent to the purposes of this appendix.

The general effect of steeping hardwoods in steam or hot water is to solubilize some of their hemicellulose content, particularly the pentosans, and to hydrolyze acetyl groups in the woody structure to free acetic acid or its salts. The extent of these effects of steeping increases with temperature (up to at least about 400° Fahrenheit) and with time. Steeping therefore promotes leaching of water-soluble organic materials from the woody structure. The leached materials are highly susceptible to anaerobic digestion. Steeping also promotes other less immediately obvious changes in the wood structure, some of which facilitate its biological digestion. Cellulose hydration and its consequent swelling are among these. The organic acids released by steeping also cause mild hydrolysis of higher-molecular-weight polysaccharides in the wood, thus increasing their susceptibility to further hydration and attack during steeping, and to biological digestion to methane in subsequent process steps. However, to achieve these effects by steeping alone would require a long steeping time, which as a consequence could increase the size of the equipment required and its capital cost.

Grinding, by itself, can significantly enhance biological digestibility of wood[19]. The extent of this enhancement is inversely proportional to the

TABLE D-III

THEORETICAL YIELD OF METHANE FROM "AVERAGE" SOFTWOOD

Chemical composition of "average" bone-dry softwood[13,14]:

	Percent by Weight
Hemicellulose, 5-carbon polysaccharides	10
Hemicellulose, 6-carbon polysaccharides	15
Cellulose	42
Lignin	30
Acetyl groups	2.6
Ash	0.4
	100

Theoretical yield of methane from anaerobically digestible materials:

	Standard Cubic Feet Per Pound of Bone-Dry Softwood
Methane from 5-carbon polysaccharides	0.72
Methane from 6-carbon polysaccharides	1.05
Methane from cellulose	2.95
Methane from acetyl groups	0.16
	4.88

particle size to which the the woody material is ground. Moreover, it has been observed that ball-milling for extended periods not only causes size reduction and a consequent increase in exposed surface area in the wood substance, but also breaks chemical bonds within its structure[20]. However, grinding wood chips to a fine particle size (for feed to the ball-mill) followed by extensive ball-milling requires a large energy input to the grinding operation on the order of fifteen horsepower-days per dry ton of chips to obtain the ball-mill feed and at least ten additional horse-power-days for ball-milling.

Incidentally, in their searches for the best pretreatments for rendering wood biologically digestible, investigators have studies the procedures used by creatures which feed on cellulose[21]. Termites, for example, mill moistened wood particles in an intricate grinding mechanism prior to submitting them for digestion by enzymes produced by protozoa in their digestion tracts. It is of interest also to note that termites cannot digest lignin.

Thus, while biological digestibility of woody plant material can be promoted by either grinding or steeping by itself, the effect of each treatment on the woody structure is different. It is not surprising that data indicate that both treatments done together -- in particular, grinding after steeping -- are better than each one used alone.

There is undoubtedly a trade-off between the amount of grinding required and the extent and conditions of steeping needed to produce woody feed material which digests satisfactorily. To illustrate the trade-offs involved, three possible sequences of grinding and steeping are examined in detail. Material and energy balances will be compared and capital costs will be estimated. First, the case of extensive steeping in steam followed by the grinding required

to reduce the wood residue to powder is examined, and then the case of extensive grinding followed by a short period of steaming. Finally, the case of extensive grinding followed by a short period of steeping in hot water is presented.

II.C.2. Extensive Steaming Followed by Grinding. Grinding after extensive steaming has been shown to offer several processing advantages. The wood substance is rendered more digestible by the two-step treatment than it is by steaming alone. Moreover, with only quite limited steaming (one hour at about 350° Fahrenheit,for instance), the energy required for grinding is significantly reduced from that which would be required in the absence of the steaming step[16]. It is reported that wood chips have a consistency resembling rotten wood after steaming[22]. They are described as friable and easily crumbled between the thumb and fingers.

A pretreatment process involving steaming followed by grinding appears to offer two additional advantages over processes involving only steaming. One of these is with respect to the biological degradability of the unsolubilized wood substance which remains after steaming, and the other is with respect to furfural formation during steaming.

Steaming renders part of the wood substance water soluble (a desired effect), while the unsolubilized fraction appears to become less susceptible to biological attack (an undesired effect). The solubilizing reactions appear to proceed more rapidly, at least during the first few hours of steaming, than do the effects which cause the unsolubilized substance to become more resistant to biological action. Thus there is a trade-off, influenced by the duration of the steaming cycle, between the extent of production of solubilized organic material which is easily digested biologically and development of biological refractoriness in the unsolubilized material. Steaming cycles

lasting only an hour or so sacrifice solubles production but avoid marked onset of biological refractoriness. The effect of the former apparently can be more than compensated by grinding after a short steaming cycle, while maintaining the benefit of the short steaming cycle with respect to the latter.

The steaming cycle not only hydrolyzes the pentosans to low-molecular-weight sugars, but also causes conversion of the latter to furfural by dehydroxylation. Some of the furfural so produced then polymerizes into higher-molecular-weight water-insoluble resins. Furfural is not readily reduced to methane by anaerobic biological action, and its polymerization products are even more resistant to conversion to methane. The low-molecular-weight pentosans from which the furfural is formed are, however, readily reduced biologically to methane. Consequently, furfural or polyfurfural formation represents a reduction in the carbon supplied by the wood substance which is available for conversion to methane. This loss has been shown to reach six percent or so of the available carbon when the steaming cycle lasts several hours[23].

Fortunately, the rate under steaming conditions at which the pentosans are hydrolyzed to simple sugars is much higher than the rate at which furfural is formed from them[23]. The furfural polymerization rate is even slower than the furfural formation rate. Thus, short steaming cycles minimize formation without seriously reducing the hydrolysis of pentosans to the lower-molecular-weight sugars which are readily converted to methane by biological action.

It is also important to suppress formation of furfural because there is evidence that it may be toxic to the anaerobic organisms which will be used in the biological methane production step.

The data available from the literature are not sufficiently detailed to permit precise estimation of the optimum trade-off between steaming and grinding, or of their combined effect on the fraction of the wood substance converted to water-soluble organic materials. However, published data[16] indicate that when twenty-to-forty-mesh aspen sawdust was steamed for an hour at about 350° Fahrenheit, 17.1 percent (dry basis) of the sawdust substance was solubilized. Grinding the resulting steamed material in a disk mill increased the solubilized fraction to 22.8 percent of the original sawdust. The particle size of the steamed and ground sawdust was not reported.

The proposed starting material for the methane production process based on juvenile wood from deciduous tree species being considered in this appendix will be wood chips rather than wood sawdust. The size of the chips will be quite variable, but some of them may be as large as about one inch square across the grain. Because of the chip size in comparison with sawdust, less than seventeen percent of their weight will be solubilized by steaming for an hour at 350° Fahrenheit; published data[17] suggest that about nine percent will actually be solubilized under these conditions. However, after grinding in a hammermill or disk mill, the particle size of the undissolved wood residue is likely to be at least as small as twenty-to-forty-mesh. In the absence of any more precise experimental information, it will be assumed for the purposes of this appendix that about seventeen percent of the wood chip weight will be solubilized by the combined effects of steaming and grinding and subsequent mixing of the resulting slurry with liquid recycled from the digesters in which methane is generated.

Of the materials dissolved from the wood during steaming, grinding and subsequent mixing with recycled anaerobic digester fluid, about four percent (based on the original dry chip weight) will be acetic acid[16]. The remaining thirteen percent (again based on the original dry chip weight) will be

assumed to have come from hydrolysis of the pentosans in the wood. Data in the literature[24] indicate that under the mildly acid condition which develops during steaming, the pentosans in hardwood are far more easily solubilized than are the polyhexoses (mainly cellulose) in the wood. Consequently, it will be assumed that none of the polyhexoses are solubilized by steaming. It will also be assumed that none of the lignin in the wood is solubilized.

A small fraction of the dissolved pentosan materials will be converted to furfural and furfural polymers during steaming. Under the proposed steaming conditions, about 0.6 percent of the wood (dry basis) will be converted to furfural[17]. The sequence of reactions leading to furfural and furfural polymer formation, assuming complete hydrolysis of the pentosan to simple pentose, is:

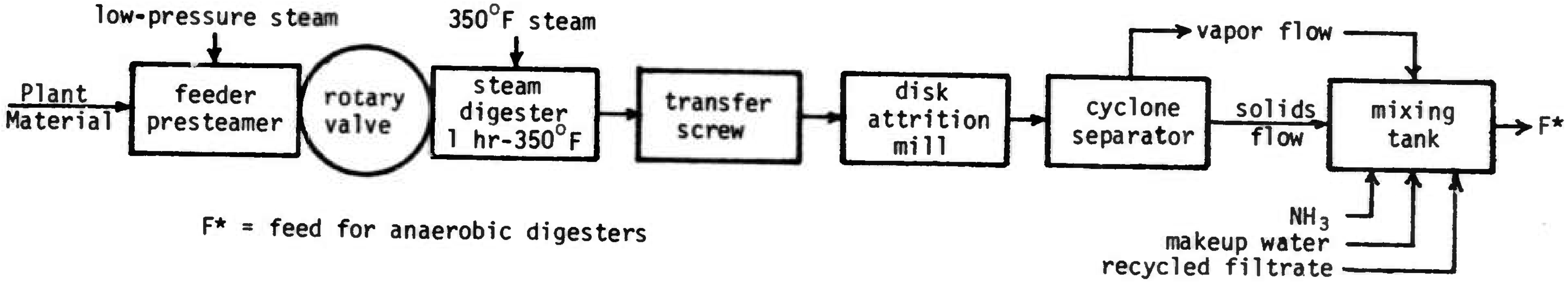
$$\underset{(C_5H_8O_4)_n}{\text{pentosan}} \xrightarrow{+nH_2O} \underset{(C_5H_{10}O_5)}{\text{n pentose}} \xrightarrow{-3nH_2O} \underset{(C_5H_4O_2)}{\text{furfural}} \xrightarrow{-mH_2O} \text{furfural polymers}$$

In view of the fact that the furfural polymerization reactions are very slow compared with the rate at which furfural is formed, it will be assumed that none of any furfural formed is polymerized during steam digestion. Because water is variously involved in the pentosan reaction chain, it must be allowed for in the material balance around the pretreatment steps. It must also be allowed for in the hydrolysis of the acetyl groups.

A schematic diagram of this process proposed for pretreating juvenile deciduous wood chips is shown in Figure D-I. The estimated material balance around the process is also shown in the figure . It is assumed that green wood chips (assumed moisture content: fifty percent based on the dry wood substance wieght) are fed to a feeder-presteamer where they are exposed to low-pressure steam (approximately saturated at atmospheric pressure). The

FIGURE D-1

EXTENSIVE STEAMING FOLLOWED BY GRINDING PRETREATMENT OF DECIDUOUS WOODY MATERIAL FLOW DIAGRAM AND ESTIMATED MATERIAL BALANCE



F* = feed for anaerobic digesters

MATERIAL BALANCE

Basis: 1 ton dry "average" plant material

FLOWS (tons)

MATERIALS	Plant Material	350°F Steam	Cyclone Effluents	NH_3	Makeup Water	Recycled Filtrate	Feed to Digester
Cellulose	0.45		0.46				0.46
Lignin	0.23		0.23				0.23
Glucomannans	0.05		0.05				0.05
Ash	0.01		0.01				0.01
Acetyl Groups	0.06		0.02				0.02
Pentosans	0.20		0.07				0.07
Recycled Inerts						?	?
Water	0.50	0.60	1.074		?	?	1.074+?
NH_3				?			?
Pentoses			0.139				0.139
Furfural			0.006				0.006
Acetic Acid			0.041				0.041

low-pressure steam typically used in the presteamer is the exhaust from the pockets of the rotary valve as it depressurizes. This steam will be neglected in the analysis. The chips are then conveyed continuously through a rotary pressure valve into the steam digester. The chip material, as it is being screw-conveyed through the steam digester, is exposed to saturated steam at about 350° Fahrenheit (120 pounds per square inch gage) for about an hour.

Chip material, condensed water and steam are discharged continuously from the steam digester into a pressurized double-revolving-disk attrition mill. The solid residue chip material will be reduced in particle size in the mill. The mill will discharge the effluent into a cyclone separator.

Because the pressure in the cyclone separator will be near atomspheric, much of the hot water in the effluent flow flashes to steam. The steam evolved at this point also carries with it a substantial portion of the lower-boiling-point organics produced from the chips during steaming and other solid and liquid material. The ground material is then delivered to a mixing tank in which the feed slurry for the biological digesters is prepared. The vapors produced during grinding and the vapor-phase steam effluent from the cyclone separator are also delivered to the mixing tank.

The mixing tank has several purposes. It is used to recombine and cool the effluent products from the cyclone and grinder prior to feeding them to the biological digesters where methane is produced. It is also used to adjust the solids content of the resulting mixture to the level required (approximately twelve percent solids) for feeding to the biological digesters. Supernatant liquid separated from the effluent from the biological digesters is recycled for this purpose and to help cool the mixture in the

mixing tank. The supernatant liquid recycle provides a major portion of the fixed nitrogen and other nutrients which must be added to the material in the mixing tank before it can be fed to the biological digesters. The liquid recycle also helps to raise the pH of the material in the mixing tank toward neutrality, which is the approximate pH required for the feed to the biological digesters.

Ammonia, or some other alkaline source of fixed nitrogen, is also introduced into the mixing tank. This material is used both to complete the pH adjustment in the tank and to provide the additional fixed nitrogen required in the feed to the methane production digesters.

The mixing tank therefore serves as a holding tank for feed to the biological digesters, as a location for adjusting its solids content, pH and microorganism nutrient levels, and as a cooler to adjust the temperature of the slurry feed to the biological digesters. For this latter purpose, it may be necessary to install cooling coils in the mixing tank. If such are found to be needed, it is proposed to use cold boiler feedwater as the coolant in the coils.

The equipment components for this proposed wood-chip pretreatment process are similar to equipment already in use in the forest-products industry. They are available from several sources, including among others, The Bauer Brothers Company, Springfield, Ohio.

Approximate gross energy requirements and uninstalled capital costs of the major pieces of equipment in this pretreatment process are listed in Table D-IV. The gross energy requirement is estimated to be about 1.4 x 10^6 Btu per oven-dry ton of plant material plus an unknown amount for the disk attrition mill. A sizeable fraction of the gross energy might be recoverable by condensing the steam flashed off in the cyclone separator

with boiler feedwater. The bare capital cost (that is,before installation) of the major elements of equipment is estimated to be about $6,200 per oven-dry ton of plant-matter processing capacity per day.

II.C.3. Extensive Grinding Followed by Steaming. If pretreatment of deciduous plant material is to involve extensive grinding and only limited steaming, it probably will be best if the grinding precedes the steaming. Less energy is required to grind cold wood chips, which are somewhat brittle, than would be needed to grind a mass of steamed wood chips in which the structure has become somewhat plasticized[25]. However, specific data are required before it can be determined definitely whether grinding before steaming rather than after is the better order.

Less solubilization of plant material occurs during a short steaming period than in the longer ones considered in the immediately preceding discussion. But the digestibility of woody material is nevertheless enhanced even by a few minutes steeping,providing it is carried out at a high-enough temperature. Data in the literature[17] from an experimental process in which part of a batch of wood chips was steamed for five minutes at 373° Fahrenheit will illustrate this point. The steamed wood chips were ground in a Wiley mill to smaller than forty mesh, and the *in vitro* digestibility of the chip residues was found to be significant -- about fifty-six percent of the organic matter in the original chips. The digestibility of chips which had been ground to one millimeter, but not steamed, was found to be only twenty-two percent of the original material. These digestibilities can not be related directly to the digestion which would occur in a methane production system, but they do indicate that digestibility can be enhanced significantly by first extensively grinding deciduous plant material and then steaming it for a few minutes. Unfortunately,the grinding energy applied to the chips is not recorded in the experimental data.

TABLE D-IV

EXTENSIVE STEAMING FOLLOWED BY GRINDING
GROSS ENERGY REQUIREMENTS AND MAJOR EQUIPMENT CAPITAL COSTS

Basis: 1 ton dry "average" hardwood chips per day

Equipment	Gross Energy Requirements Btu per ton	Capital Cost $ per day per ton (without installation)
Feeder-Presteamer	1,100 (conveyor)	
Rotary Valve	3,100 (valve drive)	
Inclined Steam Digester	1,100 (conveyor)	$5,000
	1.40×10^6 (steam)	
Cyclone Separator	-----	100
Disk Attrition Mill	*	1,000
Mixing Tank	1.22×10^4 (mixer)	150
	1.42×10^6	$6,250

* The energy requirement for the disk attrition mill is not known, and it is difficult to estimate. It will, however, be considerably less than the energy required to grind unheated wood chips.

One advantage of grinding first is that the temperature of the chips is increased by absorption of the grinding energy. Less steam is then needed in the digester to raise the chips' temperature to the desired level of 373° Fahrenheit. With an assumed energy input of seventeen horsepower-days per dry ton of plant matter in the grinding step, the ground chips will be at a temperature of about 360° Fahrenheit or so. As they leave the grinder, care must be taken that the chips have a high-enough moisture content to prevent charring and catching on fire (fifty percent moisture by weight should be more than adequate). A small flow of low-pressure steam might be introduced into the feeder-presteamer to make sure that sufficient moisture is present.

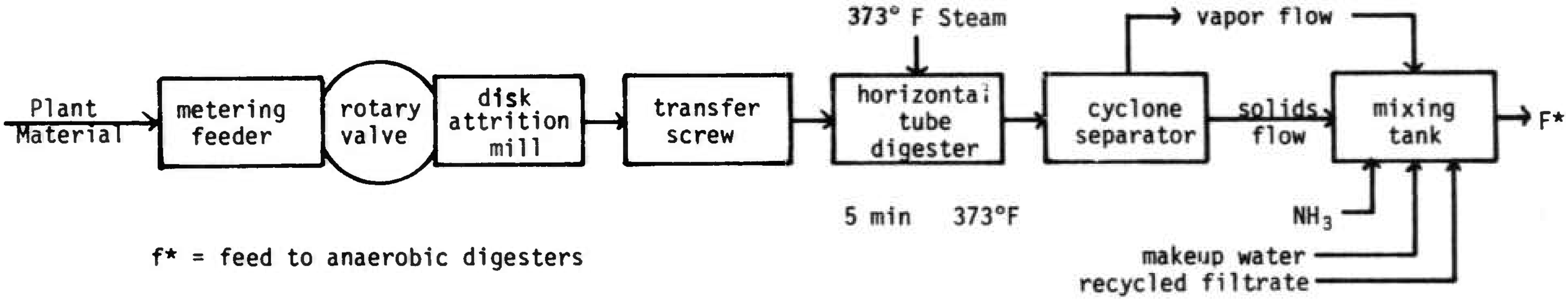
The required energy input to the grinder is a strong function of the moisture content of the wood chips. The greater the moisture content, the greater is the amount of energy required to grind the chips to a given size. For chips with the assumed moisture content of fifty percent (on a dry weight basis), the required energy input is thought to be about 17 horsepower-days per dry ton to achieve a particle size of about forty mesh or so[26]. This particle size is thought to be sufficient, but if a smaller size is required, the required energy input increases substantially. The energy used for grinding can probably be reduced significantly if the wood chips are dried first, perhaps with some source of waste heat. This would appear to be a fruitful area for experimental work to study the economic trade-offs involved.

A schematic diagram of this proposed process for pretreating juvenile deciduous wood chips is shown in Figure D-II. The estimated material balance around the process is also shown in the figure. It is assumed that green wood chips are fed to a metering feeder-presteamer which feeds the chips to a rotary valve.

FIGURE D-II

GRINDING FOLLOWED BY STEAMING PRETREATMENT OF DECIDUOUS WOODY

MATERIAL FLOW DIAGRAM AND ESTIMATED MATERIAL BALANCE



f* = feed to anaerobic digesters

MATERIAL BALANCE

Basis: 1 ton dry "average" plant material

	FLOWS (tons)						
MATERIALS	Plant Material	373°F Steam	Cyclone Effluents	NH_3	Makeup Water	Recycled Filtrate	Digester Feed
Cellulose	0.45		0.45				0.45
Lignin	0.23		0.23				0.23
Glucomannans	0.05		0.05				0.05
Ash	0.01		0.01				0.01
Acetyl Groups	0.06		0.05				0.05
Pentosans	0.20		0.20				0.20
Recycled Inerts						?	?
Water	0.50	0.05	0.55		?	?	0.55+?
NH_3	-		-	?			?
Pentoses	-		-				-
Furfural	-		-				-
Acetic Acid	-		0.01				0.01

The rotary valve feeds the chips into a pressurized double-revolving-disk attrition mill. The grinding will be done under pressure to prevent a great deal of flashing. The chips will be ground to perhaps 40 mesh or smaller.

The effluent from the disk attrition mill will be a mass of hot fine wood particles and some steam. The wood particles will be screw-conveyed into a horizontal tube digester. Saturated steam at 373° Fahrenheit and 180 psia is also introduced into the digester. The amount of steam required will be that amount which will condense to heat up the wood particles to 373° Fahrenheit plus that extra amount needed to assure thorough contact and mixing. The residence time of the wood particles within the digester will be about five minutes.

Literature data indicate that very little solubilization of wood chips takes place under these conditions of steaming -- five minutes at 373° Fahrenheit[17]. About one percent of the dry matter will be solubilized as acetic acid. Very little of the rest of the dry matter, even of the hemicelluloses, will be solubilized, and it will be assumed here that no other solubilization takes place, although some of the extractives will undoubtedly be dissolved. In the process under consideration, the woody material will be in the form of very fine particles, which may promote much more solubilization than in the case of wood chips. However, there are no firm data on solubilization as a function of particle size, a factor which needs to be studied experimentally.

From the digester, the steamed particles will be blown into a cyclone separator where steam will be flashed off from the solids. To conserve energy, the steam will be condensed by boiler feedwater. The condensed steam, which will have some organic material in it as well as entrained particles, will be fed to a mixing tank along with the solids. In the mixing tank, the feed

to the biological digesters will be prepared. The functions of the mixing tank in this pretreatment process are the same as in the extensive-steaming process previously described.

Approximate gross energy requirements and uninstalled capital costs for the major pieces of equipment in this pretreatment process are shown in Table D-V.

The gross energy requirement is about 1.2 million Btu per dry ton, which is less than the energy requirement for extensive steaming followed by grinding. Again, this calculation does not allow for energy conservation and energy recycle.

The bare equipment cost is about $3,200 per daily dry ton of capacity, which is considerably less than the cost of the first proposed pretreatment process. The residence time of the ste. 'ng step is the apparent influential factor in determining these costs. The few data available seem to indicate that the two processes are approximately equal in enhancing the biological digestibility of woody plant material,but for conformation this supposition will have to be investigated experimentally. However, at this point, the preferred pretreatment process is to grind the material extensively first, followed by a short steaming at an elevated temperature because of its smaller gross energy requirement and lower capital cost than would be the case for the process involving extensive steaming followed by grinding described in section II.C.2.

<u>II.C.4. Extensive Grinding Followed by Steeping in Hot Water.</u> In all of the literature on preparation of woody plant matter for animal feed by steeping, the wood chips are invariably steamed, usually in an autoclave to which steam is introduced for a desired period of time. At least some of the steam will

condense, if only to heat up the wood chips. Thus, the chips are contacted by both steam and condensed water. In the batch systems typically used by these experimenters, some of the chips may well have been immersed in hot water rather than steam.

The question thereupon arises whether there is a difference in effect between steeping in hot water and steeping in steam. Data on degradation of wood show that steeping in hot water leads generally to greater solubilization than steeping in steam for the same conditions of temperature and time[27]. Unfortunately, these data do not contain enough detail to permit a precise estimation of the fraction of wood solubilized under various conditions, particularly at relatively short steeping times.

However, an estimate has been made of the performance and capital cost of a pretreatment process consisting of extensive grinding followed by steeping in hot water. Of particular interest is the comparison of the capital cost of this process with the cost of a process involving grinding and steaming. The steaming process necessarily involves a steam digester as well as a mixing tank for the preparation of the digester feed slurry. For the hot-water process, the mixing tank, which is already sized to provide a half-hour residence time, is built to operate at the higher temperature and pressure and thus to serve as the steeping tank, also.

The process flow for the hot-water process, which is shown in Figure D-III, is very similar to the flow for the steaming process. However, after the wood chips have been ground, the fine wood particles drop from the grinder, which is located directly above the mixing tank, into that tank, eliminating the need for a transfer screw conveyor.

The mixing tank will have several functions. One function is to provide a

TABLE D-V

EXTENSIVE GRINDING FOLLOWED BY STEAMING
GROSS ENERGY REQUIREMENTS AND MAJOR BARE EQUIPMENT CAPITAL COSTS

Basis: 1 ton dry "average" hardwood chips per day

Equipment	Energy Requirements Btu per ton	Capital cost $ per ton per day (without installation)
Feeder-Presteamer	1,100 (conveyor)	
Rotary Valve	3,100 (valve drive)	
Disk Attrition Mill	1.04×10^6 (drivers)	$3,000
Horizontal Tube Digester	1,100 (conveyor) 1.20×10^5 (steam)	
Cyclone Separator	-----	
Mixing Tank	1.22×10^4 (mixer)	150
	1.18×10^6	$3,150

holding volume to allow thorough wetting out of the ground wood particles to take place. Suggested operating conditions for the tank are one half-hour residence time, a temperature of 373° Fahrenheit, and a pressure of about 180 psia. As a result of the grinding operation, the wood particles will have already been heated to close to this temperature. No data appear to be available for estimating the amount of solubilization which will take place under these conditions. The material balance in Figure D-III is developed assuming that one percent of the wood, as acetyl groups, will solubilize, although greater solubilization will probably occur.

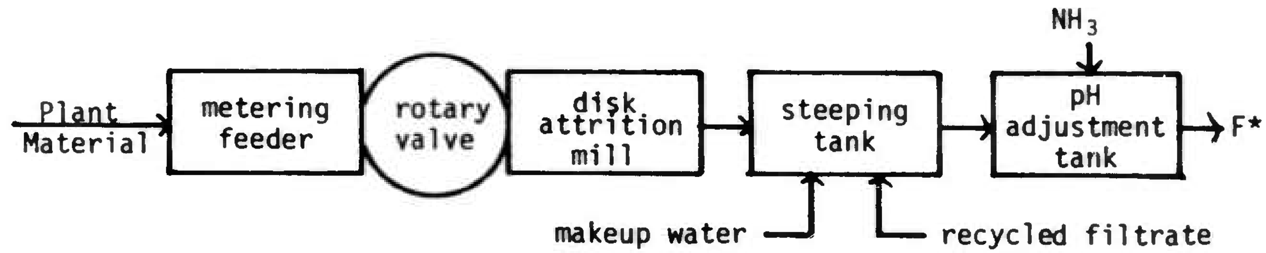
Another function of the mixing tank is to mix various streams with the ground wood particles to obtain a feed slurry of the proper solids content for pumping into the digester. Supernatant liquid separated from the digester effluent is recycled for this purpose, and this liquid also provides a major portion of the fixed nitrogen and other nutrients which must be added to the feed. This recycled filtrate and any makeup water needed must be heated to the tank temperature, and this can be accomplished with heat exchange with the slurry exiting from this steeping tank, which must be cooled down from 373° Fahrenheit to the proper feed temperature before being fed to the digester. The required feed temperature is 140° Fahrenheit,or a little higher to compensate for heat loss from the digester.

Two functions which are carried out in the mixing tank in the pretreatment process involving steaming are the adjustment of pH to near neutrality and the addition of necessary nutrients such as phosphorus and fixed nitrogen. In the hot-water process, these two functions will have to be carried out in another vessel, probably a smaller additional mixing tank. Solubilization is aided by a low pH so that it is desirable to operate the large mixing tank at as low a pH as occurs naturally through solubilization of the acetyl groups contained in the wood.

FIGURE D-III

GRINDING FOLLOWED BY STEEPING IN HOT WATER PRETREATMENT OF DECIDUOUS WOODY

MATERIAL FLOW DIAGRAM AND ESTIMATED MATERIAL BALANCE



F* = Feed to anaerobic digesters

MATERIAL BALANCE

Basis: 1 ton dry "average" plant material

MATERIALS	FLOWS (tons) Plant Material	Makeup Water	Recycled Filtrate	NH_3	Digester Feed
Cellulose	0.45				0.45
Lignin	0.23				0.23
Glucanamans	0.05				0.05
Ash	0.01				0.01
Acetyl Groups	0.06				0.05
Pentosans	0.20				0.20
Recycled Inerts	-		?		?
Water or Steam	0.50	?	?		0.50+
NH_3	-			?	?
Pentoses	-				-
Furfural	-				-
Acetic Acid	-				0.01

Since at least some of the required neutralization of the steeped wood particles can be accomplished by using ammonia or some other suitable nitrogen compound as the nitrogen-supplying nutrient, the addition of nitrogen to the feed slurry is best accomplished in the pH-adjustment tank.

Approximate gross energy requirements and bare equipment capital costs for the major pieces of equipment in this pretreatment process are shown in Table D-VI.

The gross energy requirement is about 1.1 million Btu per dry ton, which is about 10% less than the energy required for steaming the ground wood particles. The estimated bare equipment capital cost is a little less than $3,000 per daily ton of capacity, or about $200 or 6% less than the estimated capital cost for the steaming process.

The pretreatment process which involves hot water appears to be as satisfactory as the process involving steaming instead of steeping. However, this hot-water process uses less energy and costs somewhat less than the steaming process.

<u>II.C.5. Conclusion</u>. Of the pretreatment processes studied, the proce . which involves extensive grinding followed by steeping in hot water appears to be the best process to recommend, from the viewpoints of both energy usage and capital cost. The influence of pretreatment process upon digester operation and cost must be considered also, however.

TABLE D-VI

EXTENSIVE GRINDING FOLLOWED BY STEEPING IN HOT WATER
ENERGY REQUIREMENTS AND CAPITAL COSTS

Basis: 1 ton dry "average" hardwood chips per day

Equipment	Energy Requirements Btu per ton	Capital cost $ per ton per day (without installation)
Feeder-Presteamer	1,100 (conveyor)	$2,500
Rotary Valve	3,100 (valve drive)	
Disk Attrition Mill	1.04×10^6 (drivers)	
Steeping Tank	1.22×10^4 (mixer)	300
Mixing Tank	1.22×10^4 (mixer)	150
	1.07×10^6	$2,950

II.D. Material Balance for Anaerobic Digestion of Woody Material

II.D.1. General. Three different pretreatment processes have been described, and each is presumed to produce plant material which can be digested to produce methane with equal facility in the anaerobic digesters. These pretreatment processes have been compared in section II.C. with respect to the material balances around them and their energy requirements and capital costs. As a result of this comparison, one particular pretreatment process, extensive grinding followed by steeping in hot water, appears to be preferred. However, the preferred process can be determined only after the anaerobic digester operation and any possible influence of the pretreatment process on it have been examined. For example, the increased relative solubilization in the extensive steaming process, which is the most expensive, will allow a higher digester loading and, consequently, a smaller digester volume.

The effect of each pretreatment process on digester operation is examined by estimating the material balance around the digester. The material-balance calculations proceed in the same manner for all three pretreatment processes so that only one such calculation is presented in detail. Indeed, because the amount of solubilization is assumed to be the same in the steam steeping and the hot-water steeping processes, the material balances for them are very nearly the same, the only differences being in their process steam requirements and in the materials flows to the mixing tank or tanks. The material balance for the process involving steeping in hot water is described in detail, followed by summaries of the material balances for the steeping-in-steam and extensive-steaming processes.

The solids content of the feed slurry to the digesters should be as high as possible to make the digester volume as small as possible at a constant solids retention time. The maximum solids content is limited by the pumpability of the slurry, and this limit is assumed to be twelve percent by weight of suspended solids in the slurry. In calculating how much filtrate can be recycled to reach this solids content in the feed slurry, the feed solids flow and the solids remaining in the filtrate (assumed to be 0.5 percent as a first approximation) must be considered. These recycled solids include solid inert material (ash and lignin), solid cellulosic material, and biological organisms.

Sufficient nitrogen must be added to the mixing tank to provide the proper carbon-to-nitrogen ratio in the digester feed for the microorganisms. For good digestion, this ratio should be about twenty; the carbon-to-phosphorus ratio should be about one hundred. The amount of carbon in the feed is first calculated, and then the total amount of nitrogen needed. The amount of nitrogen in the recycled filtrate is calculated and taken into consideration to determine the net amount of nitrogen which must be added to the mixing tank.

The anaerobic digestion data from the literature which are most applicable to the digestion of pretreated woody material are for digestion of a kraft paper pulp powder[10]. According to these data, digestion occurs quite rapidly, reaching 88.8 percent in ten days and 93.3 percent in fifteen. At thirty days, digestion reached 93.4 percent of the input cellulose, indicating that a certain residual amount of the cellulose, about 6.6 percent, was quite refractory. The digestion culture in these experiments was carefully maintained with more than enough nutrients for the microorganisms. These data are assumed to be representative of a well-operated digester, and for pretreated woody material, it is assumed that ninety-three percent of the cellulose and all the hemicelluloses and acetyl groups

will be digested in fifteen days. The residual digestible material is therefore assumed to be cellulose. Actually, pretreated woody material may digest even more rapidly than the kraft pulp powder, because the former contains hemicelluloses and acetyl groups which are rapidly digestible, whereas the pulp does not.

For SNG production, the loading of digestible matter to the digester (pounds of digestible material per cubic foot of digester liquid per day) is considerably higher than the loading in the kraft-pulp experiments. However, synthetic-refuse digestion studies show that the fraction of the digestible material which is actually digested is independent of loading at constant retention time in the digester[9]. The literature also indicates that anaerobic-digester loading can be as high as over one pound of digestible material per cubic foot of digester liquid per day if the digester operation is carefully maintained and controlled[4,28]. The loading is considerably less than this limit in the SNG production process because of the limit on the solids content previously mentioned of the plant-material slurry fed to the digester.

The yields of gas and bacterial cell material are calculated separately for each component of the plant material to be digested according to the model reaction equations and then summed together. Each model equation specifies the amounts of fixed nitrogen and water entering into the reaction, the amount of water being calculated to close the overall material balance (an approximation). The growth yield coefficient (mass of bacteria formed per unit mass of plant material digested) varies with the type of material being digested. The amount of plant material utilized for microorganism production depends on the energy released by the fermentation[29]. The conditions of fermentation also influence the yields coefficient--for example, the type of compound supplying the nitrogen.

The yield coefficient for acetic acid is taken as 0.036 pounds of bacterial cells per pound of substrate consumed. The formula for bacteria is assumed to be $C_5H_7O_2N$. The yield coefficient for cellulose has been measured experimentally and found to be 0.104 pounds of bacterial cells per pound of substrate consumed[10], or a carbon yield coefficient of 0.124 pounds of carbon in bacterial cells per pound of carbon in cellulose. This carbon yield coefficient is assumed for all forms of cellulose and hemicellulose. Half of the carbon going to gas is assumed to be in the form of methane, and the other half as carbon dioxide, as indicated by the theoretical equations. The model reaction equations used for the material-balance calculations are shown in Figure D-IV.

The concentrations of dissolved carbon dioxide and bicarbonate in the digester effluent are calculated with the assumption that the effluent is saturated with carbon dioxide. The off-gas from the digester is assumed to be saturated with water vapor. The amount of dissolved carbon dioxide is calculated from the vapor pressure of carbon dioxide and Henry's law. Then the bicarbonate concentration is calculated from the bicarbonate equilibrium with the assumption that the digester is maintained at a pH of seven. Finally, the balance of carbon dioxide and bicarbonate within the system and the amount of carbon dioxide that is solubilized can be calculated.

The amount of fixed nitrogen which must be added to the digester feed can be calculated from the necessary carbon-to-nitrogen ratio in the feed, the amount of nitrogen used to produce bacterial cells, the nitrogen in the digester effluent, and the nitrogen recycled in the filtrate from the digester effluent filter.

The amount of alkali which must be added to the digester feed to maintain the pH in the digester at seven can be calculated as the amount needed to neutralize the carbon dioxide produced which leaves the digester in the form of bicarbonate in the digester effluent. The assumption is made that the volatile-organic-acid concentration within the system is very low, which was the case for the experiments with kraft pulp previously mentioned. Hence, the amount of volatile acids in the effluent requiring neutralization can be assumed to be negligible.

The effluent from the anaerobic digester goes to a vacuum filter where its suspended solids are partially dewatered prior to being recycled to the plantation. The filtrate from the filter is recycled to the mixing tank where the feed slurry to the digester is prepared. The performance of the vacuum filter cannot be estimated precisely, because the characteristics of the filter cake formed which influence filter performance greatly are unknown. However, filter performance can be estimated from typical filter data for sludges produced in wastewater treatment plants.

It is assumed that the solids capture efficiency of the filter is ninety percent, and the practical cake solids content which can be obtained is twenty-five percent. A typical yield of solids from a vacuum filter operating on wastewater digester effluent is 6 $lb/ft^2/hr$, and this yield figure is assumed.

The calculations for estimating the material balance around a system consisting of the plant-material pretreatment process, the anaerobic digester and the digester effluent filter, in which the pretreatment process consists of grinding the raw plant material and then steeping it in hot water, are described in the next subsection.

FIGURE D-IV

MODEL REACTION EQUATIONS FOR ANAEROBIC DIGESTION OF DECIDUOUS WOODY PLANT MATERIAL

Hydrolysis of Acetyl Groups to Acetic Acid:

$$\begin{array}{ccccl} CH\ COO_3 & + & H_2O & \longrightarrow & CH_3COOH + \text{Net change in weight of the woody raw material.} \\ 1\ \text{lb} & & 0.305\ \text{lb} & & 1.017\ \text{lb} \end{array}$$

Fermentation of Acetic Acid:

$$\begin{array}{cccccccccccc} CH_3COOH & + & N & \longrightarrow & \text{Bacterial cells} & + & CH_4 & + & CO_2 & + & H_2O \\ 1\ \text{lb} & & 0.0045\ \text{lb} & & 0.036\ \text{lb} & & 0.254\ \text{lb} & & 0.698\ \text{lb} & & 0.016\ \text{lb} \end{array}$$

Fermentation of Pentosans:

$$\begin{array}{ccccccccccc} C_5(H_2O)_4 & + & N & + & H_2O & \longrightarrow & \text{Bacterial cells} & + & CH_4 & + & CO_2 \\ 1\ \text{lb} & & 0.0132 & & 0.088\ \text{lb} & & 0.106\ \text{lb} & & 0.265\ \text{lb} & & 0.730\ \text{lb} \end{array}$$

Fermentation of Cellulose and Glucomannans:

$$\begin{array}{ccccccccccc} C_6(H_2O) & + & N & + & H_2O & \longrightarrow & \text{Bacterial cells} & + & CH_4 & + & CO_2 \\ 1\ \text{lb} & & 0.0129\ \text{lb} & & 0.065\ \text{lb} & & 0.104\ \text{lb} & & 0.260\ \text{lb} & & 0.714\ \text{lb} \end{array}$$

Fermentation of Pentose:

$$\begin{array}{ccccccccccc} C_5(H_2O) & + & N & \longrightarrow & \text{Bacterial cells} & + & CH_4 & + & CO_2 & + & H_2O \\ 1\ \text{lb} & & 0.0115\ \text{lb} & & 0.093\ \text{lb} & & 0.234\ \text{lb} & & 0.649\ \text{lb} & & 0.036\ \text{lb} \end{array}$$

II.D.2. Material Balance for Digestion Process Involving Grinding Followed by Steeping in Hot Water. The basis for the material-balance calculations is one ton (oven-dry weight) of deciduous woody plant material charged to the pretreatment process. The plant material as charged to the process, however, is not oven-dry--it is assumed to contain half a ton of moisture per ton of oven-dry material charged. The material balance is shown in Figure D-V. Some of the estimates required for the calculations are taken from Figure D-III.

II.D.2.a. The Steeping and pH-Adjustment Tanks. Estimation of the water to be added to the steeping tank to make up the feed slurry to the digester involves the recycled filtrate from the vacuum filter. Because the suspended solids content of this stream is not known for the first calculation, an approximation must be used, and it was assumed at first that this solids content is 0.5 percent. After the first calculation, a revised number can be used for subsequent calculations. The recycle stream will be in balance when the assumed recycled suspended material is equal to the suspended solids in the vacuum-filter filtrate recycled to the mixing tank. The final calculations are described here. The nitrogen input N to the pH-adjustment tank is assumed to be negligible for the purposes of this calculation.

Solids in ground plant material (from Figure D-III): 0.99 tons
Water and solubles in ground plant material (from Figure D-III): 0.51 tons

Suspended solids in recycled filtrate and makeup water added to the mixing tank: $0.0057\ W_r$ tons,
where W_r is the total tons of water added to the steeping tank from makeup water and the recycled filtrate.

Calculate amount of water W_r needed to make up slurry of twelve percent concentration in suspended solids:

$$0.12 = \frac{0.99 + 0.0057W_r}{0.99 + 0.0057W_r + 0.51 + W_R}$$

$$W_r = 7.045 \text{ tons}$$

Total weight into digester: $0.99 + 0.51 + 0.040 + 7.045 = 8.585$ tons

Density of slurry (water @ 140°F and solids @ sp. gr. 1.2): 62.4 lb/ft^3

Volume of feed slurry: $\frac{8.585 \times 2000}{62.4} = 275 \text{ ft}^3$

Digestible-material concentration in feed to digester: assume the biodigestible materials in the plant material are cellulose, pentosans, glucomannans, acetyl groups and acetic acid. Their total weight is 0.76 per ton of oven-dry plant material: $\frac{0.76 \times 2000}{275} = 5.53$ pounds per cubic foot of slurry to the digester.

II.D.2.b. Anaerobic Digester.

Digester loading: $\frac{5.53}{15} = 0.369$ pounds per day per cubic foot of liquid in the digester.

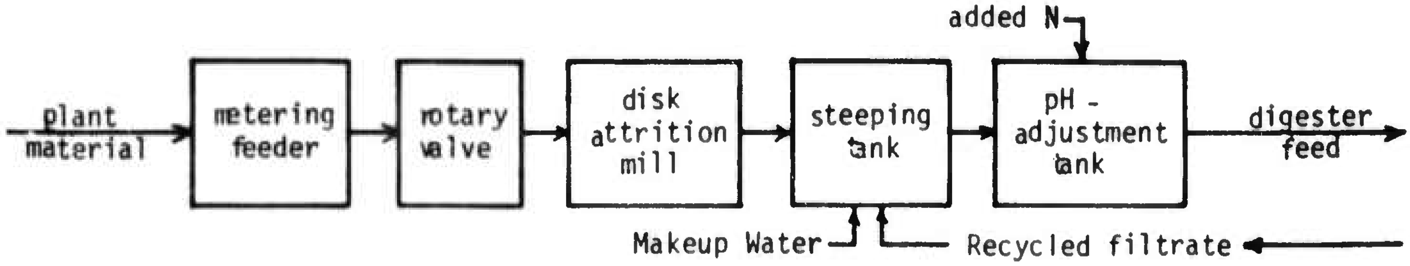
Total substrate in: 0.76 tons

Substrate digested: $0.76 \times 0.93 = 0.707$

Substrate left (cellulose): 0.053 tons

FIGURE D-V

MATERIAL BALANCE FOR METHANE PRODUCTION
BY ANAEROBIC DIGESTION OF DECIDUOUS WOODY MATERIALS
EXTENSIVE GRINDING FOLLOWED BY STEEPING IN HOT WATER



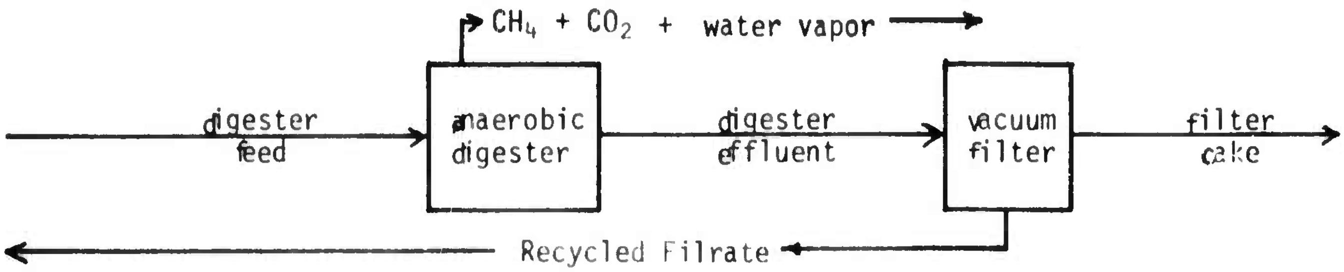
MATERIAL BALANCE
Basis: 1 ton oven-dry plant material

------------------------------FLOWS (tons)------------------------------

MATERIALS	Plant Material	Makeup Water	Recycled Filtrate	Added N	Digester Feed
Suspended Solids:					
Lignin	0.23	-	-	-	0.23
Ash	0.01	-	-	-	0.01
Cellulose	0.45	-	-	-	0.45
Pentosans	0.20	-	-	-	0.20
Glucomannans	0.05	-	-	-	0.05
Acetyl Groups	0.06	-	-	-	0.05
Bacterial Cells	-	-	-	-	-
Recycled Inerts	-	-	0.04	-	0.04
Water or Steam	0.50	0.756	6.289	-	7.545
Dissolved Materials:					
Acetic Acid	-	-	-	-	0.01
Carbon Dioxide	-	-	0.0019	-	0.0019
Bicarbonate	-	-	0.0134	-	0.0134
Nitrogen	-	-	0.0069	0.01	0.0169
Gas:					
Water Vapor	-	-	-	-	-
Methane	-	-	-	-	-
Carbon Dioxide	-	-	-	-	-
Total Weight:	1.50	0.756	6.351	0.01	8.617
Volumes:					
Liquid	-	-	207 ft^3	-	275 ft^3
Gas (total)	-	-	-	-	-
Methane (dry)	-	-	-	-	-

FIGURE D-V (continued)

MATERIAL BALANCE FOR METHANE PRODUCTION
BY ANAEROBIC DIGESTION OF DECIDUOUS WOODY MATERIALS



MATERIAL BALANCE

Basis: 1 ton oven-dry plant material

---------------------------FLOWS (tons) ---------------------------

MATERIALS	Digester Feed	Digester Effluent	Filter Cake	Recycled Filtrate
Suspended Solids:				
Lignin	0.23	0.23	0.207	0.023
Ash	0.01	0.01	0.009	0.001
Cellulose	0.45	0.053	0.048	0.005
Pentosans	0.20	-	-	-
Glucomannans	0.05	-	-	-
Acetyl Groups	0.05	-	-	-
Bacterial Cells	-	0.071	0.064	0.007
Recycled Inerts	0.04	0.040	0.037	0.004
Water or Steam	7.545	7.381	1.092	6.289
Dissolved Materials:				
Acetic Acid	0.01	-	-	-
Carbon Dioxide	0.0019	0.0023	0.0003	0.0019
Bicarbonate	0.0134	0.0163	0.0024	0.0134
Nitrogen	0.0169	0.0081	0.0012	0.0069
Gas:				
Water Vapor	-	0.102	-	-
Methane	-	0.188	-	-
Carbon Dioxide	-	0.516	-	-
Total Weight	8.617	8.617	1.461	6.351
Volumes:				
Liquid	275 ft^3	252 ft^3	45 ft^3	207 ft^3
Gas (total)	-	22,100 SCF	-	-
Methane (dry)	-	8,900 SCF	-	-

The production of methane, carbon dioxide, and bacterial cells is calculated according to the model reaction equations in Figure D-IV. The equations are also used to calculate the amount of water entering into the reactions and the amount of nitrogen used by the bacteria.

Percent suspended solids in digester effluent:

Total suspended solids out = 0.404 tons

Total weight out = 7.785 (neglecting CO_2, HCO_3 and fixed nitrogen) tons.

$$\text{Percent solids} = \frac{0.404 \times 100}{7.785} = 5.2 \text{ percent}$$

The specific gravity of this mixture will be approximately 1.01. The volume of liquid effluent out was calculated with this assumption.

The digester gas is assumed to be saturated with water vapor at atmospheric pressure at 140°F, and the digester effluent is assumed to be saturated with carbon dioxide. The net amount of carbon dioxide which leaves the digester in the effluent, either as dissolved carbon dioxide or bicarbonate, is calculated and subtracted from the carbon dioxide produced.

These calculations of the carbon dioxide balance and the amount dissolved depend on the amounts of dissolved carbon dioxide and bicarbonate in the filtrate recycled to the steeping tank. This latter quantity depends in turn on the performance of the vacuum filter.

<u>II.D.2.c. Vacuum Filter</u>. The material balance for the vacuum filter is shown in Figure D-V. It should be noted that the filter, under the assumed conditions, does not yield quite enough filtrate for the required amount of recycle. Some fresh water will have to be used, or the vacuum filter will have to operate under different conditions to obtain more filtrate.

The volume of filtrate recycled shown in Figure D-V is calculated using the density of water at 140°F, which is 61.4 pounds per cubic foot.

<u>II.D.2.d. Calculation of Carbon Dioxide Balance.</u> Calculation of dissolved carbon dioxide and bicarbonate:

$$\text{mole fraction } CO_2 \text{ in solution} = \frac{\text{partial pressure } CO_2}{\text{Henry's Law constant}}$$

$$X_{CO_2} = \frac{0.402 \text{ atm}}{3410 \text{ (@ 140°F) atm}}$$

$$= 1.18 \times 10^{-4}$$

Concentration of CO_2 in solution = 6.56×10^{-3} gmoles/liter

$$(HCO_3^-) = \frac{(CO_2)5.19 \times 10^{-7} \text{ (@ 140°F)}}{(H+)}$$

Assume digester is maintained at pH of 7:

$$(HCO_3^-) = \frac{6.56 \times 10^{-3} \times 5.19 \times 10^{-7}}{10^{-7}}$$

$$= 0.0340 \text{ gmoles/liter}$$

Volume of recycled filtrate: 207 ft^3

Dissolved CO_2 in recycled filtrate: $\frac{0.018 \times 207}{2000} = 0.0019$ tons

Bicarbonate in recycled filtrate: $\frac{0.129 \times 207}{2000} = 0.0134$ tons

Dissolved CO_2 in digester effluent: $\frac{0.018 \times 252}{2000} = 0.0023$ tons

Bicarbonate in digester effluent: $\frac{0.129 \times 252}{2000} = 0.0163$ tons

CO_2 produced that is solubilized: $\frac{(0.0163 - 0.0134)\ 44}{61} + (0.0023 - 0.0019)$

$= 0.0025$ tons

Amount of alkali that must be added to system to maintain pH:

$$\frac{(0.0163 - 0.0134)}{61} = 4.8 \times 10^{-5} \text{ ton equivalents}$$

II.D.2.e. Nitrogen and Phosphorus Balance Calculations:

Carbon in digestible substrate:

Cellulose	0.204
Glucomannans	0.022
Pentosans	0.032
Acetyl Groups	0.008
Pentoses	0.056
Acetic Acid	0.016
	0.338 tons carbon

Necessary nitrogen (as N) in feed: $\frac{0.338}{20} = 0.0169$ tons

Nitrogen in bacterial cells: $0.124 \times 0.071 = 0.0088$ tons

Nitrogen in effluent: $0.0169 - 0.0088 = 0.0081$ tons

Nitrogen in recycled filtrate: $0.0081 \times \frac{6.289}{7.381} = 0.0069$ tons

Nitrogen which must be added to mixing tank: $0.0169 - 0.0069 = 0.01$ tons

Phosphorus must also be provided. The nitrogen-to-phosphorus ratio must be about five. The amount of phosphorus used in making bacterial cells is not known. The assumption is made that the same proportions apply to phosphorus as nitrogen; that is, the same proportion is recycled. Therefore, the amount of phosphorus which must be added to the mixing tank is:

$$\text{Amount phosphorus to be added (as P): } \frac{0.01}{5} = 0.002 \text{ tons}$$

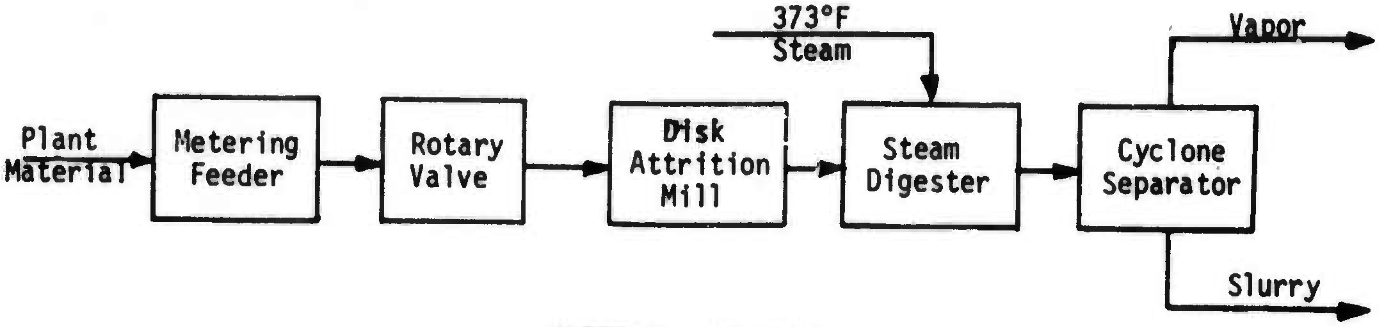
II.D.3. Material Balances for Other Pretreatment Processes. The material balances for the other two pretreatment processes considered are calculated in exactly the same fashion as outlined in the preceding subsection, beginning with the material balance for the plant material after the assumed amount of solubilization, which is dependent on the pretreatment, has taken place.

The material balance for the process involving grinding followed by steeping in steam is almost identical with the material balance for the hot-water process. This material balance is shown in Figure D-VI.

The material balance for the process involving extensive steaming followed by grinding is shown in Figure D-VII. More solubilization takes place in this process so that the feed slurry contains dissolved pentoses and furfural as well as acetic acid. The pentoses are readily digested, but furfural is believed to be essentially inert. Because the filtrate from the vacuum filter is recycled, the furfural in the system builds up until the amount escaping from the system in the filter cake is equal to the furfural produced in the pretreatment process. It must be assumed that the estimated concentration of furfural which is built up in the system is not toxic; no data exist which indicate otherwise.

FIGURE D-VI

MATERIAL BALANCE FOR METHANE PRODUCTION
BY ANAEROBIC DIGESTION OF DECIDUOUS WOODY MATERIALS
EXTENSIVE GRINDING FOLLOWED BY STEEPING IN STEAM



MATERIAL BALANCE

Basis: 1 ton oven-dry plant material

FLOWS (tons)

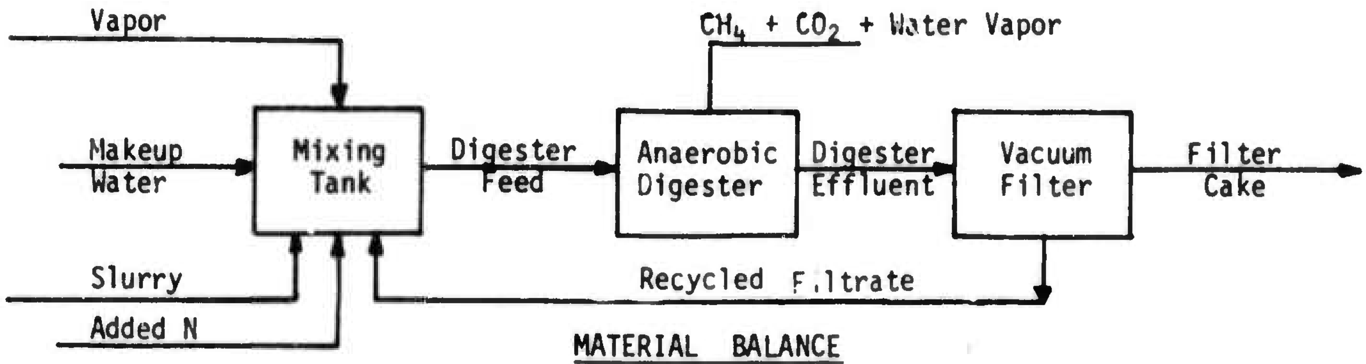
MATERIALS	Plant Material	373°F Steam	Cyclone Effluents
Suspended Solids:			
Lignin	0.23	-	0.23
Ash	0.01	-	0.01
Cellulose	0.45	-	0.45
Pentosans	0.20	-	C.20
Glucomannans	0.05	-	0.05
Acetyl Groups	0.06	-	0.05
Bacterial Cells	-	-	-
Recycled Inerts	-	-	-
Water or Steam	0.50	0.05	0.55
Dissolved Materials:			
Acetic Acid	-	-	0.01
Carbon Dioxide	-	-	-
Bicarbonate	-	-	-
Nitrogen	-	-	-
Gas:			
Water Vapor	-	-	-
Methane	-	-	-
Carbon Dioxide	-	-	-
Total Weight:	1.50	0.05	1.55
Volumes:			
Liquid	-	-	-
Gas (total)	-	-	-
Methane (dry)	-	-	-

FIGURE D-VI (continued)

MATERIAL BALANCE FOR METHANE PRODUCTION

BY ANAEROBIC DIGESTION OF DECIDUOUS WOODY MATERIALS

EXTENSIVE GRINDING FOLLOWED BY STEEPING IN STEAM



MATERIAL BALANCE

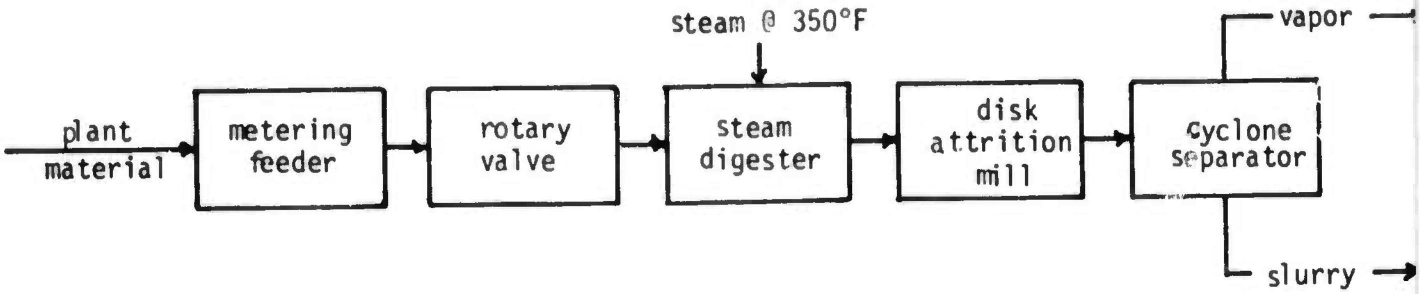
Basis: 1 ton oven-dry plant material

--------------------FLOWS (tons)--------------------

MATERIALS	Added N	Makeup Water	Recycle Filtrate	Digester Feed	Digester Effluent	Filter Cake
Suspended Solids:						
Lignin	-	-	0.023	0.23	0.23	0.207
Ash	-	-	0.001	0.01	0.01	0.009
Cellulose	-	-	0.005	0.45	0.053	0.048
Pentosans	-	-	-	0.20	-	-
Glucomannans	-	-	-	0.05	-	-
Acetyl Groups	-	-	-	0.05	-	-
Bacterial Cells	-	-	0.007	-	0.071	0.064
Recycled Inerts	-	-	0.004	0.04	0.040	0.036
Water or Steam	-	0.706	6.289	7.545	7.381	1.092
Dissolved Materials						
Acetic Acid	-	-	-	0.01	-	-
Carbon Dioxide	-	-	0.0019	0.0019	0.0023	0.0003
Bicarbonate	-	-	0.0134	0.0034	0.0163	0.0024
Nitrogen	0.01	-	0.0069	0.0169	0.0081	0.0012
Gas:						
Water Vapor	-	-	-	-	0.102	-
Methane	-	-	-	-	0.188	-
Carbon Dioxide	-	-	-	-	0.516	-
Total Weight:	0.01	0.706	6.351	8.617	8.617	1.461
Volumes:						
Liquid	-	-	207 ft^3	275 ft^3	252 ft^3	45 ft^3
Gas (total)	-	-	-	-	22,100 SCF	-
Methane (dry)	-	-	-	-	8,900 SCF	-

FIGURE D-VII

MATERIAL BALANCE FOR METHANE PRODUCTION BY ANAEROBIC DIGESTION OF DECIDUOUS WOODY MATERIALS EXTENSIVE STEAMING FOLLOWED BY GRINDING



MATERIAL BALANCE

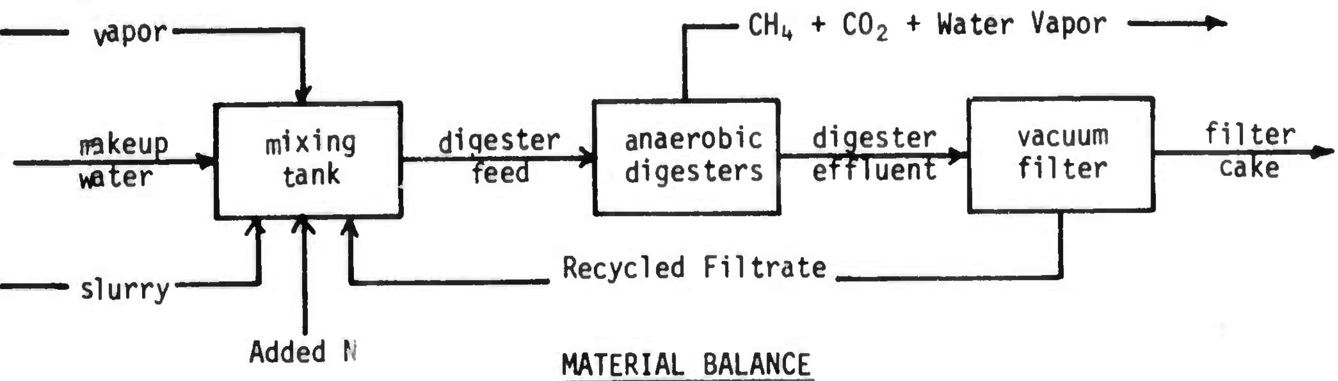
Basis: 1 ton oven-dry plant material

-----FLOWS (tons)-----

MATERIALS	Plant Material	350°F Steam	Cyclone Effluents
Suspended Solids:			
Lignin	0.23	-	0.23
Ash	0.01	-	0.01
Cellulose	0.45	-	0.46
Pentosans	0.20	-	0.07
Glucomannans	0.05	-	0.05
Acetyl Groups	0.06	-	0.02
Bacterial Cells	-	-	-
Recycled Inerts	-	-	-
Water or Steam	0.50	0.60	1.074
Dissolved Materials:			
Pentoses	-	-	0.139
Furfural	-	-	0.006
Acetic Acid	-	-	0.041
Carbon Dioxide	-	-	-
Bicarbonate	-	-	-
Nitrogen	-	-	-
Gas:			
Water Vapor	-	-	-
Methane	-	-	-
Carbon Dioxide	-	-	-
Total Weight	1.50	0.60	2.10
Volumes:			
Liquid	-	-	-
Gas (total)	-	-	-
Methane (dry)	-	-	-

FIGURE D-VII (continued)

MATERIAL BALANCE FOR METHANE PRODUCTION
BY ANAEROBIC DIGESTION OF DECIDUOUS WOODY MATERIALS
EXTENSIVE STEAMING FOLLOWED BY GRINDING



MATERIAL BALANCE

Basis: 1 ton oven-dry plant material

	FLOWS (tons)					
MATERIALS	Added N	Makeup Water	Recycled Filtrate	Digester Feed	Digester Effluent	Filter Cake
Suspended Solids:						
Lignin	-	-	0.023	0.23	0.23	0.207
Ash	-	-	0.001	0.01	0.01	0.009
Cellulose	-	-	0.005	0.46	0.053	0.050
Pentosans	-	-	-	0.07	-	-
Glucomannans	-	-	-	0.05	-	-
Acetyl Groups	-	-	-	0.02	-	-
Bacterial Cells	-	-	0.007	-	0.070	0.063
Recycled Inerts	-	-	0.003	0.03	0.040	0.036
Water or Steam	-	0.162	5.081	6.267	6.129	1.098
Dissolved Materials:						
Pentoses	-	-	-	0.139	-	-
Furfural	-	-	0.028	0.034	0.034	0.006
Acetic Acid	-	-	-	0.041	-	-
Carbon Dioxide	-	-	0.0015	0.0015	0.0019	0.0004
Bicarbonate	-	-	0.0107	0.0107	0.0136	0.0029
Nitrogen	0.0102	-	0.0067	0.0169	0.0081	0.0014
Gas:						
Water Vapor	-	-	-	-	0.102	-
Methane	-	-	-	-	0.186	-
Carbon Dioxide	-	-	-	-	0.513	-
Total Weight	0.0102	0.162	5.138	7.390	7.392	1.464
Volumes:						
Liquid	-	-	1[illegible] ft^3	[illegible]36 ft^3	212 ft^3	45 ft^3
Gas (total)	-	-	-	-	22,000 SCF	-
Methane (dry)	-	-	-	-	8,800 SCF	-

Because greater solubilization appears to take place in the extensive steaming process, the digester loading can be greater, while the limit on feed slurry suspended solids content is maintained. The feed slurry volume, and hence digester volume for the same retention time, is significantly less for this process. The feed slurry volume is 236 cubic feet per oven-dry ton of plant material versus 275 cubic feet per oven-dry ton of plant material for each of the other steeping processes. The digester volume is, as a result, almost fourteen percent smaller.

II.E. Process Design for the Pretreatment and Digestion Systems

II.E.1. General. With the material balances worked out for the anaerobic digestion of woody plant material, a process design can be developed for economically sized pretreatment and digestion processing trains. Information on equipment operating capacity and conditions, and equipment cost and energy requirements has been obtained on available equipment which would be suitable for this purpose.

Information obtained on equipment manufactured by Bauer Brothers, Inc., for the forest-products industry shows that a large processing train for treating woody plant material has a capacity of 200 dry tons of plant material per day. This capacity has been adopted for a single processing train producing a mixture of methane and carbon dioxide saturated with water vapor by anaerobic digestion of woody plant material. For larger-capacity gas production plants, as many of these processing trains in parallel can be used as needed to achieve the desired capacity. However, there is probably an upper economic limit to the capacity of a single gas plant, because the area of the plantation supporting the plant will become too large to manage as a centralized operation. The cost of transporting the plant material from the furthest reaches of the plantation to the gas plant will become excessive, for example.

The major pieces of equipment in one of these processing trains and their configuration depend on the particular pretreatment process for the woody plant material, although much of the equipment is the same or perhaps differs only in size. This present section includes descriptions of these pieces of equipment and other pertinent information. Then in section II.E.3., the process designs for the three processes considered, each of which involves a different pretreatment, are presented, and the capital costs of the processes are shown to illustrate the trade-offs involved.

Purification of the gas evolved from the digester is discussed in section II.E.4., since the design of this part of the process is the same regardless of the pretreatment process used. The gas purification processes used depend on the desired quality of the gas, which depends in turn on the production schedule and associated gas storage requirements. This problem is also discussed in section II.E.4.

The energy balance is shown in section II.E.5. for the entire SNG process involving grinding followed by steeping in hot water. Means for conserving the energy used in the process are suggested.

In section II.E.6., capital and operating costs for the entire process are presented and discussed in a generalized way to allow the cost of the gas produced to be calculated for any particular army base.

II.E.2. Major Pieces of Equipment in the Pretreatment and Digestion Trains.

II.E.2.a. Metering Feeder[30]. The purpose of the metering feeder is to supply the rotary valve with a constant, metered flow of plant material by means of a screw conveyor. In passing through the feeder, the material is preconditioned by exhaust steam from the rotary valve. This steam passes through the material, heating it and driving out air. For a

capacity of 200 tons (oven-dry basis) of material per day, the feeder will require about fifteen horsepower to drive the screw conveyor. The cost of the feeder is included in the cost of the steam digester system.

II.E.2.b. Rotary Valve[31] The rotary valve, which is basically a set of pockets rotating on a shaft between inlet and outlet, conveys the plant material into either the pressurized disk attrition mill or the large steam digester, depending on the pretreatment process being considered. The power required for the valve is about ten horsepower for a pretreatment system having a capacity of 200 tons (oven-dry basis) per day. The cost of the valve is included in the cost of the steam digester system.

II.E.2.c. Large Steam Digester for Extensive Steaming[32]. For an extended period of steaming, a continuous pulp digester can be used. These digesters are available with a capacity of up to 200 tons (oven-dry basis) per day of plant material and operate at pressures up to 150 psig. Equipment, therefore, is already available for operating at the conditions desired for one of the pretreatment processes, namely one hour at 350° Fahrenheit and 120 psig. The screw conveyor used to move the plant material through the digester requires about fifteen horsepower. The cost of this type of steam digester including the metering feeder and a rotary valve, but before installation, is about two million dollars.

II.E.2.d. Disk Attrition Mill[33]. The double-revolving-disk attrition mill grinds the plant material into small particles about 40 mesh or so in size. The mill is pressurized with steam from the steam digester or steeping tank, depending on the pretreatment process, to maintain a steam atmosphere to help prevent charring the plant material during grinding. The capacity of the mill is determined on a volumetric basis. The largest mills available have a capacity of 200 tons (oven-dry basis) per day. The required grinding energy (about seventeen horsepower-days per dry ton of

plant material) is provided by two 1700 horsepower motors. The cost of the mill may be included in the cost of the steam digester system, but by itself its cost is between $200,000 to $300,000 before installation.

II.E.2.e. Steam Digester for Steaming After Grinding[34]. For contacting the ground wood particles with steam at an elevated temperature and pressure, a horizontal steam digester is already available from the forest-products industry. The largest unit available has a capacity of 200 tons (oven-dry basis) at a five-minute retention time. This equipment is a tubular pressure vessel containing a rotating screw for moving the material through it. The screw requires about fifteen horsepower. A complete steam digester system consisting of a metering feeder, rotary valve, disk attrition mill, steam digester, and cyclone separator costs between $500,000 and $600,000 before installation. The steam digester alone costs about $100,000.

II.E.2.f. Cyclone Separator. For those two pretreatment processes in which plant material, after pretreatment, is discharged from the attrition mill or the steam digester and immediately reduced to atmospheric pressure, a cyclone separator is used for the pressure reduction step. Steam and other vapors flash in the separator. Heat is recovered from the flashed material and the resulting condensate and uncondensed vapors are conveyed to the mixing tank. The cost of the separator is usually included in the cost of the steam digestion system, but if it is not, it will cost about $15,000 before installation.

II.E.2.g. Steeping Tank. In the process involving steeping in hot water, the feed slurry for the anaerobic digesters is made up in a steel mixing tank which is operated at 373° Fahrenheit and 180 psia to provide the steeping conditions. The vessel is sized to provide a residence time of half an hour--its capacity would be about 10,300 gallons for a pretreatment process having a capacity of 200 tons (oven-dry basis) of plant material per day. The vessel would be shop fabricated and would cost about $40,000[35], plus about $5,000 additional for insulation. For complete mixing of the

vessel contents, a mixer consuming about 40 horsepower is required, costing about $10,000[36].

<u>II.E.2.h. Mixing Tank</u>. All three processes require an ordinary steel mixing tank, either for making up the feed slurry or for merely adjusting the slurry pH before the feed is introduced into the digester. The tank volume is about 10,300 gallons, and the tank is not pressurized. Its cost is estimated from a standard reference[37] and a price-time series to adjust the price to December, 1974. The cost is about $15,000 plus an additional $10,000 for the mixer required, which requires 40 horsepower.

<u>II.E.2.i. Anaerobic Digesters</u>. An anaerobic-digester volume of about one million cubic feet is required for processing the plant material from a pretreatment system having a capacity of 200 tons (oven-dry basis) per day, if the retention time in the digester is fifteen days. This volume can be supplied by four digesters, each having a diameter of 110 [illegible] and a sidewater depth of twenty-six feet. A digester of this size is about the largest these days. For complete mixing of the digester contents, four 25 horsepower mixers are required for each digester[38], giving a total mixing power requirement of 400 horsepower. The cost of the digesters is about $2.25 per cubic foot of volume for these large units. This figure was obtained by applying a price index factor to a cost obtained from a recent EPA report[39]. This cost includes construction, controls, control building, mixers, and piping within the structures.

<u>II.E.2.j. Vacuum Filter</u>. With an assumed solids yield of six pounds per square foot of filter surface per hour, which is typical for wastewater treatment plants, the filtering area required is about 1,000 square feet for an anaerobic digestion system having a daily capacity of two hundred tons (oven-dry basis) of plant material. This filtering capacity can be provided by a single filter costing about $760,000. This cost, which

includes installation and the necessary building, has been derived from estimates in a recent EPA report[39] after adjusting the EPA estimate to the price level in effect in December, 1974. A vacuum filter having this capacity will require about 150 horsepower.

<u>II.E.3. Capital Costs of Pretreatment and Anaerobic Digestion Trains</u>. Using the information on individual pieces of equipment in the preceding section, the approximate capital requirements can be estimated for pretreatment and anaerobic digestion trains based on each of the three proposed pretreatment sequences. It is assumed that the anaerobic digestibility of the pretreated plant material produced by each of the sequences is the same, and therefore the pretreatment-anaerobic digestion trains incorporating each of them can be compared on the basis of capital costs of the trains. It should be noted that the capacity of each of the trains is fixed at two hundred tons (oven-dry basis) of plant material per day by the capacity of either the largest continuous steam digester or disk attrition mill available these days.

The major pieces of equipment and their costs are listed for each of the pretreatment-anaerobic digestion trains in Tables D-VII, D-VIII and D-IX, one table being devoted to each train. The installed cost of some of the equipment has been estimated by applying an appropriate Lang factor to the uninstalled equipment cost. Lang factors allow for installation, design, building and other costs over and above the cost of uninstalled equipment in grass-roots process plants[37].

The values for Lang factors depend on whether the equipment is designed for processing fluids or solids. They are higher for the former than the latter because the former involve more process piping, instrumentation and complex tie-ins than do the latter. Characteristically, Lang factors for equipment

for processing fluids are about four times the bare equipment cost, whereas they are only about 3.8 times the cost of equipment designed for processing solid materials. These Lang factors include 0.5 to account for the cost of steam generation and distribution facilities and delivery of utilities to the equipment. Because a steam generation system will be included separately in the total estimated cost of the entire SNG production plant, the Lang factors shown in Tables D-VII, D-VIII and D-IX have been reduced to 3.5 and 3.3 for fluid-processing and solids-processing equipment, respectively.

Besides the configuration of the pretreatment equipment, the other piece of equipment which differs between the process trains shown in Tables D-VII, D-VIII and D-IX is the capacity of the anaerobic digesters. Because the extensive-steaming pretreatment process apparently produces more solubilization of the plant material than does either of the other two processes, the anaerobic digester loading for the extensive-steaming pretreatment process is higher and the digester volume correspondingly lower than for either of the other two pretreatment processes. The necessary digester volume for each case has been calculated by multiplying the digester effluent volume per dry ton of feed shown on the material balances by the retention time and the capacity of 200 tons per day, and then adding 25 percent to allow for floating-scum volume and necessary gas space.

Comparison of the three capital cost estimates shows that the extensive-grinding processes are considerably cheaper than the extensive-steaming process, which requires a large expensive steam digester, as well as a grinder anyway. The increased cost of the digesters in the steeping processes is more than offset by the savings on the steam digester. The hot-water-steeping process is cheaper than the steam-steeping process, because the necessary pressurized mixing tank costs about half as much as the steam digester. Without allowance for steam generation or gas purification, the estimated capital requirement for the hot-water-steeping process is about $2.61 per daily SCF of methane-generating capacity.

TABLE D-VII

ESTIMATED CAPITAL COST OF A PRETREATMENT AND ANAEROBIC DIGESTION TRAIN INVOLVING EXTENSIVE GRINDING FOLLOWED BY STEEPING IN HOT WATER

Process train capacity: 200 tons (oven-dry basis) of plant material per day from which 1.78×10^6 SCF of methane are produced per day.

Equipment	Equipment Cost-Uninstalled	Lang Factor	Equipment Cost-Installed
Metering Feeder Rotary Valve Disk Attrition Mill	$450,000	3.3	$1,480,000
Steeping Tank	55,000	3.5	190,000
pH-Adjustment Tank	25,000	3.5	90,000
Anaerobic Digesters (945,000 ft^3)			2,130,000
Vacuum Filter			760,000
Total Estimated Capital Cost			$4,650,000
Estimated Capital Cost per Daily SCF of Methane Production Capacity			$2.61

II.E.4. Gas Purification Train.

II.E.4.a. Gas Storage Considerations. The gas produced in the anaerobic digester is estimated to be, on the basis of present information, approximately a 50-50 mixture of methane and carbon dioxide saturated with water vapor at 140°F and at a pressure only a few inches of water above atmospheric. What further processing is necessary depends on the desired final composition of the produced gas and the gas production schedule to be followed.

For example, if pipeline-quality SNG is desired, the digester gas must be compressed and dried and have the carbon dioxide removed. On the other hand, the carbon dioxide might be left with the methane, and the digester gas might be used as a low-Btu gas after merely being dried and compressed to a pressure sufficient to pump it through the distribution system.

The gas production schedule influences the total plant production capacity and the amount of gas storage that may be necessary. For example, the plant capacity can be designed to produce the entire amount of gas needed by the army base at a constant average rate throughout the year. Storage would be needed to accumulate the excess of production over demand during the warm season and to draw upon this excess when demand exceeds production in the cold season.

It has been shown in Appendix A-Section V in the analysis of seasonal fuels demand for Fort Bragg, for instance, that the monthly percentage of the total fuels demand varies from 12.5 percent during the five coldest months to 4.7 percent during the five warmest months, the demand during the remaining two months being 7.0 percent each. By comparing this seasonal fuels demand with average monthly demand of 8.33 percent, it is possible to estimate the maximum inventory required in terms of a percentage

TABLE D-VIII

ESTIMATED CAPITAL COST OF A PRETREATMENT AND ANAEROBIC DIGESTION TRAIN INVOLVING EXTENSIVE GRINDING FOLLOWED BY STEAMING

Process train capacity: 200 tons (oven-dry basis) of plant material per day from which 1.78×10^6 SCF of methane are produced per day.

Equipment	Equipment Cost-Uninstalled	Lang Factor	Equipment Cost-Installed
Metering Feeder Rotary Valve Disk Attrition Mill Horizontal Steam Digester Cyclone Separator	$550,000	3.3	$1,820,000
Mixing Tank	25,000	3.5	90,000
Anaerobic Digesters ($945,000\ ft^3$)			2,130,000
Vacuum Filter			760,000
Total Estimated Capital Cost			$4,800,000
Estimated Capital Cost per Daily SCF of Methane Production Capacity			$2.70

of the total fuels demand which must be kept in storage if fuel is produced at a constant rate throughout the year. This maximum inventory is about 21 percent of the total annual fuels demand at Fort Bragg. With an additional reserve of one warm month's demand, storage must equal about 26 percent, which represents a very large amount of gas to store under any assumed storage pressure, particularly if the carbon dioxide is not removed before storing the gas.

Another way of compensating for the seasonal fuels demand is to make gas production follow the demand. This would perhaps be possible with the anaerobic digestion process, but the feed rate to the digesters must be changed gradually with a lead time of one to two months to permit the microorganism population to adapt to the changed operating conditions. However, to produce gas at the highest monthly demand rate, the plant capacity would have to be 150 percent of the average annual capacity required. For a considerable part of the year, the plant would have excess capacity, which would be an additional capital cost and operating expense. A load-following operation would also present operational problems for the plantation. Some storage would probably be necessary to allow for the possibility that the gas production rate cannot be changed fast enough to be in phase with a change in demand; an inventory of perhaps 5 percent of total annual demand would have to be maintained.

To avoid the expense of on-site storage or the problems involved in operating the plantation and gas plant in a load-following fashion, yet another alternative would be to produce pipeline-quality gas at a constant average rate and use the storage capacity of the gas utility. Thus, gas would be delivered to the pipeline when production exceeds demand, and gas would be taken from the pipeline in periods of high demand. In a few years when natural gas is in even shorter supply than it is these days, the gas utility is likely to have under-utilized gas

TABLE D-IX

ESTIMATED CAPITAL COST OF A PRETREATMENT AND ANAEROBIC DIGESTION TRAIN INVOLVING EXTENSIVE STEAMING FOLLOWING BY GRINDING

Process train capacity: 200 tons (oven-dry basis) of plant material per day from which 1.78×10^6 SCF of methane are produced per day.

Equipment	Equipment Cost-Uninstalled	Lang Factor	Equipment Cost-Installed
Metering Feeder Rotary Valve Inclined Steam Digester	$2,000,000	3.3	$6,600,000
Disk Attrition Mill	250,000	3.3	820,000
Cyclone Separator	15,000	3.3	50,000
Mixing Tank	25,000	3.5	90,000
Anaerobic Digesters ($795,000\ ft^3$)			1,790,000
Vacuum Filter			760,000
Total Estimated Capital Cost			$10,110,000
Estimated Capital Cost per Daily SCF of Methane Production Capacity			$5.68

storage capacity and would probably welcome the opportunity to use it. The charge for this use of the utility's storage is unknown, but this concept appears to be attractive and feasible from a number of points of view.

Designing the process to produce pipeline-quality gas also has the advantage of maintaining the ability to utilize the utility's gas as a backup supply.

The general conclusion is that a gas production plant at an army base must produce pipeline-quality SNG. This means that the gas evolved from the digester must be compressed to 1000 psia, have the carbon dioxide removed, and be dried to pipeline specifications, although not necessarily in that order. The effect of pressure on the carbon dioxide removal process must be considered, and the processing sequence optimized accordingly.

<u>II.E.4.b. Removal of Carbon Dioxide</u>. There are a number of standard processes available which can be considered for removing the carbon dioxide from the anaerobic digester gas. Each process has certain advantages in certain types of applications, depending on the desired purity of the final gas stream, contaminants in the influent gas, pressure of the influent gas, and composition of the gas to be scrubbed.

The process which perhaps is thought of first is the monoethanolamine (MEA) process in which the carbon dioxide-containing gas is scrubbed with an aqueous solution of MEA. This process is the oldest standard process for removing carbon dioxide and other acid gases from hydrocarbon gas streams. Its particular area of application is in producing high-purity effluent gas at a relatively low partial pressure of carbon dioxide.

However, this process requires a relatively high amount of steam for regenerating the absorbent. Solution circulation requirements also tend to be high because of the limit on the amount of carbon dioxide which can be absorbed per gallon of absorbent solution.

To improve on the steam and capital requirements of the MEA process, a number of processes have been developed which use absorbent solutions having a higher capacity for carbon dioxide at high pressure than does MEA[40]. Steam requirements for regeneration are considerably less, too. One such process is the Sulfinol process, in which the absorbent is an aqueous solution of Sulfolane and di-isopropyl amine. The steam requirement is about half that of a comparable MEA unit. However, the area of application for the Sulfinol process is in treating gas streams with significant amounts of various sulfur compounds. For treating high-pressure gas streams whose acid-gas content is limited to relatively pure carbon dioxide with perhaps some hydrogen sulfide, the Sulfinol process is not competitive with the processes using hot solutions of potassium carbonate with an activator of some sort[41].

Although these are several hot potassium carbonate processes for removing carbon dioxide from hydrocarbon gas streams, a process should be chosen using a solution in which the organic ingredients are biodegradable. It is planned to put solution residues into the feed to the anaerobic digesters, for pollution control and to obtain whatever gas it is possible to get from the organic ingredients. The potassium carbonate would add buffering capacity to the digester feed.

As one hot potassium carbonate process which can be used for the present application, the Benfield process appears to be suitable. The activator in the potassium carbonate solution, which is needed to increase the rate at which carbon dioxide dissolves, is diethanolamine, which should be readily

biodegradable. The steam requirement for the Benfield process is considerably less than that of the MEA process because in the regeneration of the absorbent solution, carbon dioxide can be released from the solution by depressurizing it with a minimum of heat input needed.

The efficiency of carbon dioxide absorption in the Benfield absorbent is not increased significantly if the partial pressure of the carbon dioxide is much above about 125 pounds per square inch. Thus, the benefits of using the Benfield process for removing the carbon dioxide from the 50-50 mixture with methane as compared with the MEA process are obtained if the gas mixture is compressed to no more than 300 psia. After the carbon dioxide is removed, the methane alone can be compressed from 300 psia to the required pressure of 1000 psia.

The energy requirements for a unit for one processing train producing 1.78×10^6 SCF per day of methane (and an approximately similar amount of carbon dioxide) are about 7×10^6 Btu per hour in steam, which can be anywhere between 40 and 100 pounds per square inch in pressure, and 38 kW or 51 horsepower in pumping power for a unit operating at 300 pounds per square inch[42].

The influent gas must be hot (around 250°F or so), and this condition can be attained simply by not cooling the gas completely after the last stage of compression from atmospheric pressure to 300 psia. It is assumed that the effluent gas contains one percent carbon dioxide, and that this gas would satisfactorily meet pipeline specifications, although the Benfield unit can produce purer methane if required to do so. After going through the Benfield unit, the methane will be saturated with water vapor. Before going to the glycol dehydration unit, the methane should be cooled to about 100°F, which will cause water to condense from the methane gas stream, thereby reducing its moisture content.

The investment cost of a Benfield carbon dioxide removal unit depends on its capacity. The cost of a unit sized for the capacity required for one processing train is $350,000[42]. However, most gas plants would have more than one processing train so that the Benfield unit would probably be sized to handle the effluent gas from several processing trains. A unit sized to handle four processing trains, which would produce enough gas to satisfy the annual demand of Fort Leonard Wood, for example, would cost about $924,000 or about $231,000 per processing train. A generalized correlation for the cost of a Benfield carbon dioxide removal unit for an n-train gas plant is shown in Table D-X.

II.E.4.c. Gas Compression. One processing train using 8.33 tons (oven-dry basis) of plant material per hour will produce about 74,100 SCF of methane or about 148,000 SCF of dry gas mixture per hour. This gas is to be compressed from atmospheric pressure to 300 pounds per square inch absolute before the carbon dioxide is removed from the gas mixture. This compression can be done in a standard centrifugal two-stage compressor with intercooling between stages. If the gas is first cooled to 100° Fahrenheit after leaving the digester and is cooled again to 100° Fahrenheit after the first stage of compression, about 850 horsepower will be required, assuming a seventy-five percent efficiency for the compressor. After each stage, the temperature of the gas will be about 333° Fahrenheit.

To save on capital expense, the compressor can be sized to compress the gas from more than one train, a compressor having 3400 horsepower connected being suitable for four trains, for instance. However, to allow for maintenance and to avoid shutting down the entire plant on compressor failure, two compressors of 1700 horsepower each will be included in the design of a typical four-train plant. The cost of the compressors is estimated from a recent reference[43] and a price index to adjust the estimates to December 1974.

A generalized cost for the two compressors in an n-train plant, each having a capacity of (850 n/2) horsepower, is shown in Table D-X.

After most of the carbon dioxide is removed from the gas mixture, the methane containing about one percent carbon dioxide is compressed from 300 pounds per square inch absolute to 1,000 pounds per square inch absolute. This compression can be done with a standard single-stage centrifugal compressor. If the gas is first cooled to 100° Fahrenheit after leaving the Benfield unit, about 160 horsepower will be required, assuming a seventy-five percent efficiency for the compressor.

Two compressors are again assumed for an n-train plant, each having a capacity of (160 n/2) horsepower. A generalized cost for these compressors is shown in Table D-X.

II.E.4.d. Heat Exchangers. Two water-cooled heat exchangers are included for cooling the gas stream in the gas purification process, in addition to the intercooling in the two-stage compressor. The functions of these heat exchangers are to cool the carbon dioxide-methane gas mixture before it is compressed on its way to the Benfield unit, and to cool the methane coming from the Benfield unit before the gas stream is compressed to the final pressure of 1000 psia.

The heat-transfer areas required for these exchangers have been estimated by using typical overall heat-transfer coefficients. Approximate costs were obtained from reference 43 and a price index to adjust the estimates to December 1974. Although these costs are only approximate and are not based on detailed designs, they do indicate the magnitude of the contribution of the heat exchangers to the capital cost of the gas purification train.

TABLE D-X

ESTIMATED CAPITAL COST OF A GAS PURIFICATION PROCESS FOR AN N-TRAIN GAS PLANT

Basis: An n-train gas plant processing 200n tons (oven-dry basis) of deciduous woody material per day from which 1.78×10^6 n SCF of methane are produced per day.

Equipment	Equipment Cost-Uninstalled	Lang Factor	Equipment Cost-Installed
Heat Exchanger	$\$5{,}000\ n^{0.65}$	3.5	$\$17{,}500n^{0.65}$
Compressor	$2x1.46x130{,}000(\frac{n}{2})^{0.82}$	3.3	$\$710{,}000n^{0.82}$
Benfield Carbon Dioxide Removal Unit			$\$350{,}000n^{0.7}$
Heat Exchanger	$6{,}000\ n^{0.65}$	3.5	$21{,}000n^{0.65}$
Compressor	$2x1.46x37{,}000(\frac{n}{2})^{0.82}$	3.3	$202{,}000n^{0.82}$
Glycol Dehydration Unit	$15{,}000n^{0.6}$		$52{,}500n^{0.6}$
Total Estimated Capital Cost			The sum of the entries above

For the gas produced from one processing train, the heat exchanger before the two-stage compressor should have an area of about 200 square feet, and this exchanger will cost about $5,000 before installation. The heat exchanger before the methane compressor should also have an area of about 200 square feet and will cost about $6,000. This exchanger costs more than the first because of the higher pressure range involved. Because the water condensing out of the gas streams will be in contact with carbon dioxide and therefore contain carbonic acid, a material other than carbon steel should probably be used for the tubes in these exchangers.

For a gas plant having more than one pretreatment-anaerobic digestion train, the heat exchangers should be designed to handle all the gas processed by the gas purification unit, and economies of scale will result. Generalized costs for these exchangers for an n-train plant are shown in Table D-X.

II.E.4.e. Drying the Methane Stream. After the carbon dioxide is removed from the methane, which is then compressed to 1,000 psia, the methane must be dried to meet pipeline specifications. The moisture content should be no more than five pounds of water per million standard cubic feet. Although a substantial part of the water vapor picked up in the Benfield unit at 250°F is condensed by cooling of the gas to 100° Fahrenheit and compressing it to 1000 psia, further drying is necessary.

An effective means for drying the SNG is a glycol dehydration unit. The damp SNG is contacted with triethylene glycol in an absorber. The water vapor is absorbed by the glycol, which is then regenerated by heating it in a stripper tower.

The unit is of standard design and is simple to operate with relatively little consumption of energy. The regeneration steam required to dry the gas from one processing train is about forty pounds per hour (a reboiler capacity of 2000 Btu per gallon of solution multiplied by five gallons of solution per pound of water removed and three pounds of water removed per hour and divided by the heat of vaporization of the steam, 826 Btu per pound of steam which is saturated at about 400°F). Pumping power required is less than one-half horsepower.

The capital cost of the glycol dehydration unit is relatively modest. A unit sized to handle the gas from one processing train costs about $15,000 before installation for a skid-mounted unit[44]. As with the carbon dioxide-removal unit, the cost per processing train is reduced with a larger unit sized to handle several trains. A generalized cost for a unit for an n-train plant is shown in Table D-X.

II.E.4.f. Material Balance and Capital Cost. The material balance for the gas purification system is shown in Figure D-VIII. The basis for the balance is one ton (oven-dry basis) of plant material processed through the pretreatment and anaerobic digestion system. The figure shows the changes in condition and composition of the gas stream as it is processed. The amounts of water condensed from the various cooling stages are also shown.

The capital cost of the major equipment in the gas purification process are summarized in Table D-X. For those items for which only the equipment cost is known, this cost has been multiplied by an appropriate Lang factor to allow for various other costs, direct and indirect, involved in building the purification system. The generalized costs shown in the table should hold with reasonable accuracy for a purification train serving as many as ten processing trains, or a capacity of 2000 tons (oven-dry basis) per day of deciduous woody material.

II.E.5. Energy Balance for the Entire SNG Process. The energy balance for the entire process which involves the preferred pretreatment of grinding intensively followed by steeping in hot water can now be described with the aid of the energy requirements for the individual components.

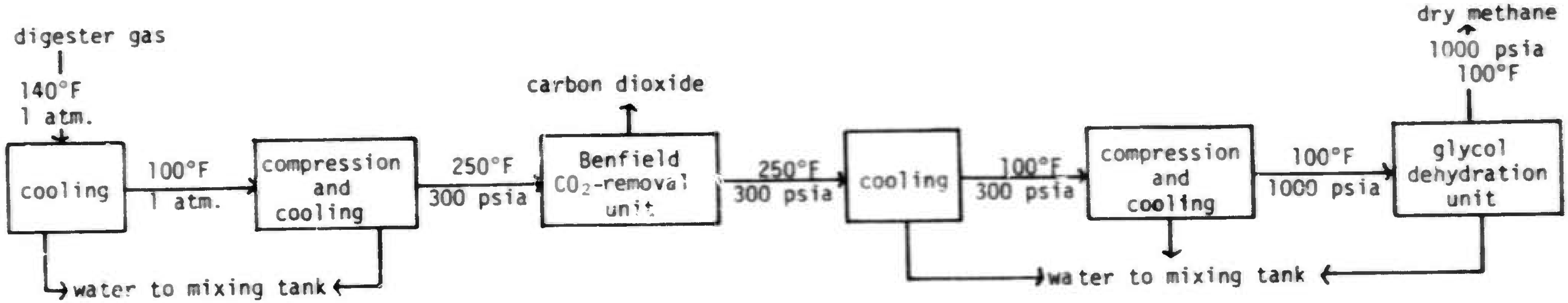
The energy balance for the process also depends on how certain elements of the process are designed for energy recovery and energy reuse. For example, the flows going into the steeping tank must be at 373° Fahrenheit, and the effluent from the tank must be cooled before entering the pH-adjustment tank. The net energy required for the steeping tank depends on how the heat-exchange system is designed. A suggested design for the heat exchange system between the entering and exiting flows is shown in Figure D-IX.

The temperatures around the first heat exchanger were calculated for an eighty-percent-effective heat exchanger and the required flows. The temperatures of the cooling water and recycled filtrate are assumed to be 60° and 140° Fahrenheit, respectively. The temperature of the digester feed stream going to the pH-adjustment tank is 152°F, a value calculated to provide enough heat to the anaerobic digester above 140°F to allow for the latent heat of vaporization of the water vapor escaping with the gaseous effluent from the digester. Heat loss from the digester itself was estimated using approximate heat-transfer coefficients for a wastewater digester. The loss was found to be negligible. When the digester is operated properly, the anaerobic digestion reactions are thermally neutral, neither giving off nor requiring much heat.

Under these conditions for the heat-exchange system around the steeping tank, about 5.30×10^6 Btu per hour must be added to the filtrate-recycle-plus-makeup-water stream entering the steeping tank for one processing train. To provide this heat by condensation of 400°F saturated steam requires 3.21 tons of steam per hour.

FIGURE D-VIII

MATERIAL BALANCE FOR PURIFICATION OF THE GAS MIXTURE EVOLVED FROM ANAEROBIC DIGESTERS PROCESSING DECIDUOUS WOODY MATERIAL



MATERIAL BALANCE

Basis: 1 ton oven-dry plant matter

FLOWS (tons)

	Methane	Carbon Dioxide	Water
Digester Gas	0.188	0.516	0.102
Water from Cooling	-	-	0.073
Gas to Compression	0.188	0.516	0.029
Water from Cooling	-	-	0.023
Gas to Benfield Unit	0.188	0.516	0.006
Carbon Dioxide off-gas	-	0.511	?
Methane to Cooling	0.188	0.005	0.024
Water from Cooling	-	-	0.0233
Methane to Compression	0.188	0.005	6.8×10^{-4}
Water from Cooling	-	-	4.8×10^{-4}
Methane to Dehydration	0.188	0.005	2.0×10^{-4}
Water from Dehydration	-	-	1.8×10^{-4}
Product Gas (8,990 SCF)	0.188	0.005	2.2×10^{-5}

The costs for the three heat exchangers have been estimated for approximate heat-transfer areas calculated on the basis of assumed typical overall heat-transfer coefficients. The first heat exchanger for the effluent and the filtrate-recycle-plus-makeup-water stream requires about 1500 square feet and costs about $12,000. The second heat exchanger requires about 1000 square feet and costs about $9,000. The steam-heated third heat exchanger may need about 250 square feet and cost about $5,000. To get the total installed costs of these exchangers, these capital costs should be multiplied by a Lang factor of 3.5. These figures are all very approximate, but they indicate the magnitudes of the areas and costs involved.

The energy required for one processing train is shown in Figure D-X. The shaft power required is 5,116 horsepower. The steam needed is 3.23 tons per hour of saturated steam at about 400° Fahrenheit and 3.85 tons saturated at about 300° Fahrenheit. A savings in primary energy can be realized if the process steam needed is used first to generate electricity. In this way, electricity can be produced without the associated cost and inefficiency of condensing steam. The steam must be condensed in the process for heat anyway so that any electricity generated from this steam prior to using the steam for process purposes is obtained at a very high efficiency.

Also shown in Figure D-X is a proposed system for generating the required process steam and for obtaining electrical power from it. The steam turbine would have a takeoff for 400°F steam, and the remainder of the steam would be exhausted from the turbine at 300°F with perhaps five percent moisture. The amount of steam has been increased from the minimum required because of this moisture in the 300°F steam. A total of 3.85 tons per hour of 300°F saturated steam must be available for the Benfield carbon dioxide removal unit.

FIGURE D-IX

HEAT EXCHANGE AROUND THE STEEPING TANK

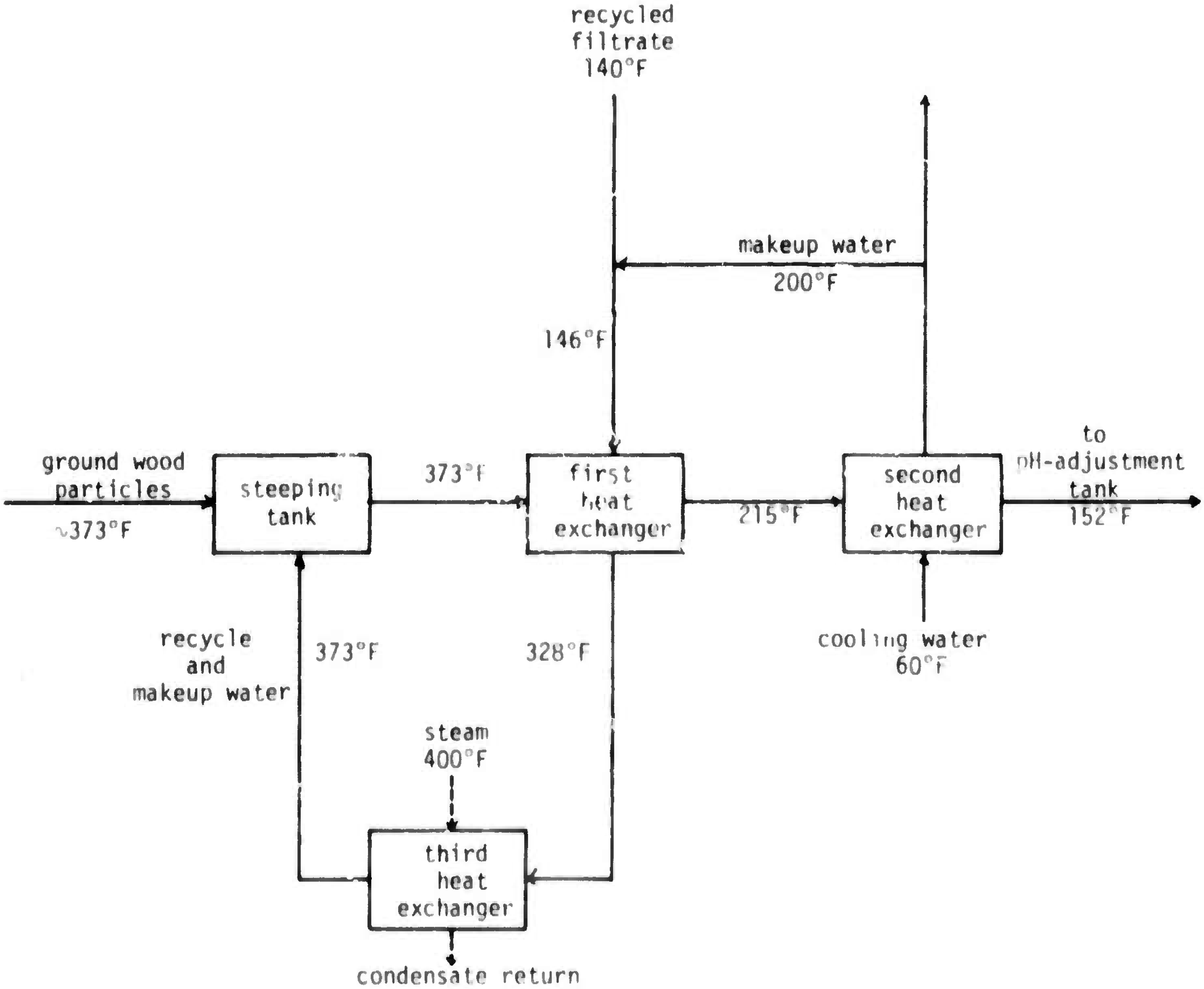
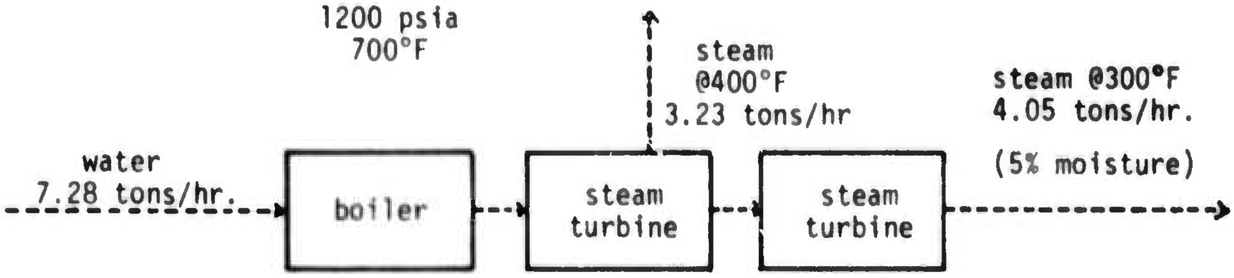


FIGURE D-X

ENERGY REQUIREMENTS FOR DIGESTION OF DECIDUOUS WOODY MATERIAL

Basis: One processing train with a capacity of 200 tons (dry-basis) per day.

Steam Generation



Electrical Generation: 589 kW (790 hp)

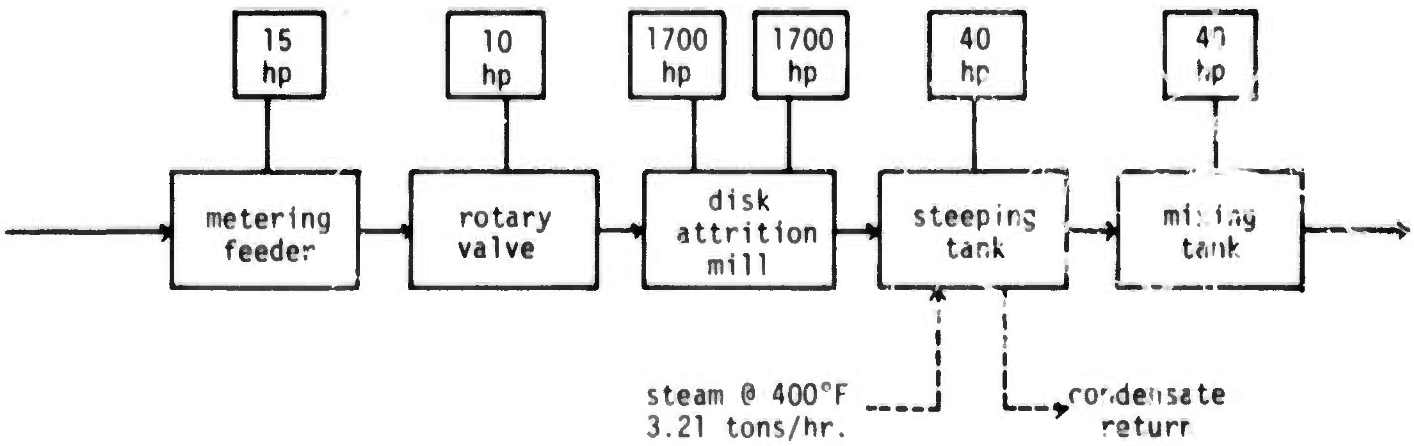
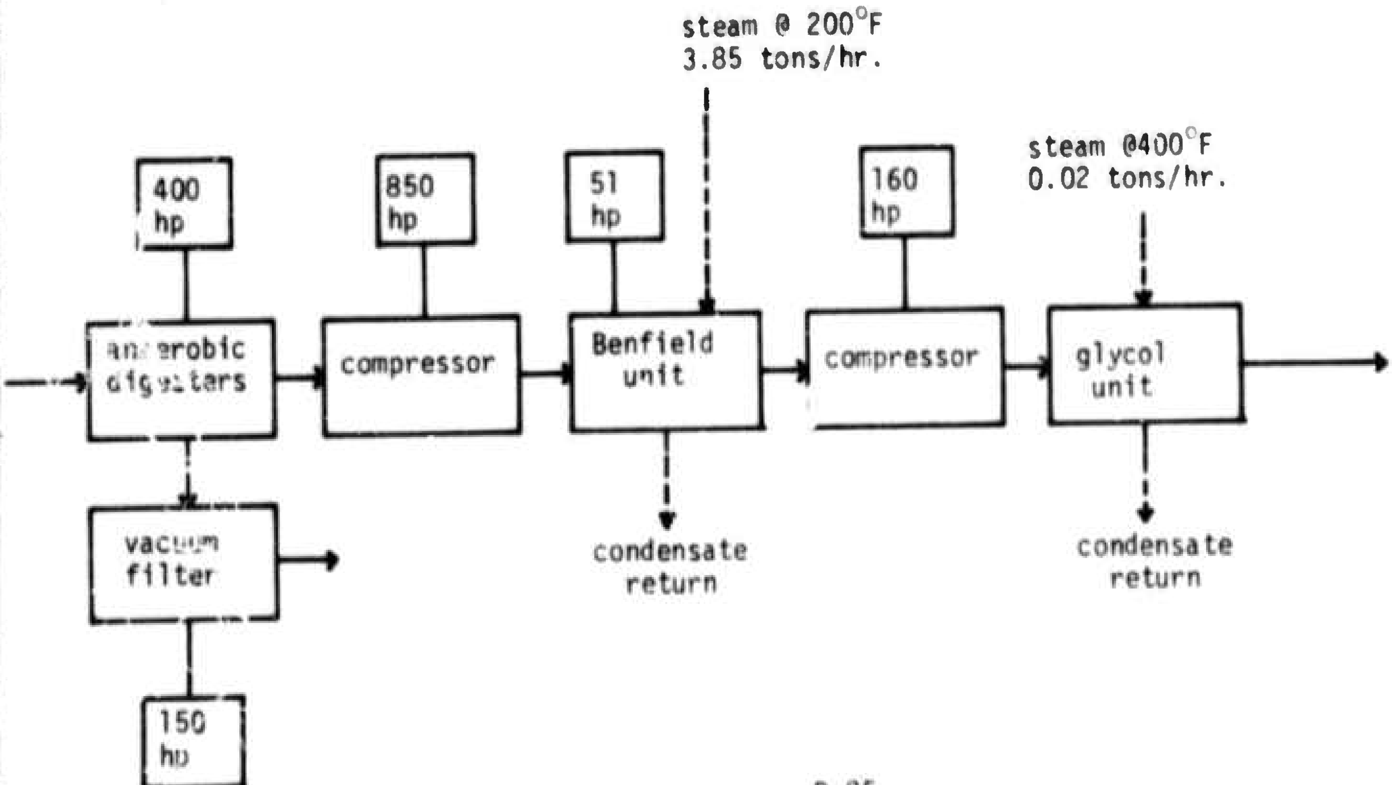


FIGURE D-X
(continued)

ENERGY REQUIREMENTS FOR DIGESTION OF DECIDUOUS WOODY MATERIAL

Basis: One processing train with a capacity of 200 tons (dry-basis) per day.



The electrical capacity which could be provided by this proposed system is about 589 kilowatts or about 790 horsepower. This amount of power is sufficient for the motors on the mixers on the steeping and pH-control tanks and the anaerobic digesters--a total of 480 horsepower, and for the motors on the vacuum filter and on the methane compressors. It would be advantageous to use the power from the steam to generate electricity to run electric motors rather than to use the steam directly in steam turbines because of the problems of piping steam to a number of small turbines and the inefficiencies of these small turbines. Besides, with electric motors, utility electricity can be used as a backup power supply.

The estimated overall energy balance for the entire process is shown in Table D-XI. There are three energy inputs--the energy in the plant material processed, the energy used in the boiler to generate process steam and some electricity, and the primary fuel used by the utility supplying the remainder of the electricity required. There is one energy output--the energy in the SNG produced. The energy efficiency expressed as the energy output divided by the energy input is about 50 percent.

A more significant efficiency is the ratio of the energy output as SNG to the input of conventional energy; since Energy Plantation fuel is inexhaustible and perpetually renewable, this energy does not really count as a debit against the national supply of exhaustible fuels. The ratio is the measure of the effectiveness of the proprosed process in stretching and conserving the limited supply of conventional fuels. This ratio can be used to compare other processes claiming to conserve conventional fuels. For the SNG Energy Plantation process, this ratio is 142 percent.

To supply the process steam, it has been assumed that fossil fuel is used in the boiler. In the specific cost calculations for the two forts, coal has been assumed because it is cheaper (at least currently) than plantation fuel. It does not appear feasible to supply 100 percent of each base's requirements with SNG derived from plantation fuel without having to supply the process steam boiler, too, so that firing the boiler too only compounds the problem of finding sufficient land. Since coal is not currently used very much at either fort, coal-

TABLE D-XI

ENERGY BALANCE FOR AN SNG PRODUCTION CAPACITY OF 200 TONS (OVEN-DRY BASIS) PER DAY

Basis: one hour's operation

ENERGY INPUTS:

Energy in woody plant material processed -

$$8.33 \frac{\text{tons}}{\text{hr}} \times 2000 \frac{\text{lb}}{\text{ton}} \times 5800 \frac{\text{Btu}}{\text{lb}} = 96.63 \times 10^6 \frac{\text{Btu}}{\text{hr}}$$

Energy used by boiler -

Energy in steam - Energy in condensate

$$\frac{19.07 \times 10^6 - 4.61 \times 10^6}{0.65} = 22.25 \times 10^6 \frac{\text{Btu}}{\text{hr}}$$

(65 percent boiler efficiency assumed)

Primary fuel used by utility to generate electricity -

5116	horsepower total
- 790	generated from process steam
4326	horsepower from utility electricity

$$4326 \text{ hp} \times \frac{1 \text{ kW}}{1.341 \text{ hp}} \times 9{,}300 \frac{\text{Btu}}{\text{kWh}} = 30.00 \times 10^6 \frac{\text{Btu}}{\text{hr}}$$

Total energy input 148.9×10^6 Btu/hr.

ENERGY OUTPUT:

Energy in SNG produced -

$$74{,}100 \frac{\text{SCF}}{\text{hr}} \times 1000 \frac{\text{Btu}}{\text{SCF}} = 74.1 \times 10^6 \frac{\text{Btu}}{\text{hr}}$$

ENERGY EFFICIENCY:

$$\frac{74.1 \times 10^6}{148.9 \times 106} \times 100 = 50\%$$

supply logistics would have to be developed. If sufficient oil can be found for this purpose, oil can be used in the boiler.

The energy balance shown in Table D-XI does not include the energy from conventional sources used in the plantation. However, as noted in Appendix C, this requirement is only 2.3×10^6 Btu for producing the 8.33 tons (oven-dry basis) of plant material required per hour for the SNG production system represented in Table D-XI.

<u>II.E.6. Total Capital and Operating Costs</u>. The estimated total capital cost for the entire process is summarized in Table D-XII. Costs are shown for a four-train, a five-train, and an n-train plant. For a multi-train plant, the estimated capital cost for the pretreatment and digestion units is simply the cost for one train multiplied by the number of trains as these units are installed in parallel to obtain the desired SNG plant capacity. Included in the table is an estimated cost for a steam generation system with distribution. The total estimated capital cost shown in the table includes the cost of the equipment, installation, instrumentation, piping, electrical, buildings, yard improvements, service facilities, as well as the indirect costs of engineering, construction expense, and contractor's fee.

As shown in the table, the total capital cost per daily SCF of capacity is not influenced significantly by the number of trains in the plant. The reason is that the larger part of the capital cost is in the parallel pretreatment and digestion trains for which there is no economy of scale to be obtained in larger plants.

The operating cost of an SNG plant is shown in Table D-XIII in general terms. Factors influencing the operating costs which can vary widely depending on the locality of the SNG plant are the cost of boiler fuel and the cost of electricity. Another factor which influences the operating cost considerably is the cost of plant material.

TABLE D-XII

TOTAL ESTIMATED CAPITAL COSTS FOR SYSTEMS PRODUCING SNG FROM DECIDUOUS WOODY MATERIAL

	4	5	n
Raw Material required-tons (oven-dry basis) per day	800	1,000	200n
SNG capacity, 10^6 SCF per day	7.12	8.90	1.78n
Equipment	Installed Capital Cost		
Metering Feeders Rotary Valves Disk Attrition Mills	5,920,000	7,400,000	1,480,000n
Steeping Tanks	760,000	950,000	190,000n
Heat Exchangers	360,000	450,000	90,000n
pH-Adjustment Tanks	360,000	450,000	90,000n
Anaerobic Digesters	8,520,000	10,650,000	2,130,000n
Vacuum Filters	3,040,000	3,800,000	760,000n
Heat Exchanger	43,000	50,000	$17,500n^{0.65}$
Compressors	2,213,000	2,657,000	$710,000n^{0.82}$
Benfield Unit	924,000	1,080,000	$350,000n^{0.7}$
Heat Exchanger	52,000	60,000	$21,000n^{0.65}$
Compressor	630,000	756,000	$202,000n^{0.82}$
Glycol Dehydration Unit	121,000	138,000	$52,500n^{0.6}$
Steam Generation and Distribution	2,343,000	2,801,000	$773,000n^{0.8}$
Total Estimated Capital Cost	$25,286,000	$31,242,000	the sum of the above
Estimated Capital Cost per Daily SCF of SNG Production Capacity	$3.55	$3.51	

The manpower requirements for a four-train plant, a five-train plant, and an n-train plant are shown in Table D-XIV. Shown in the table are the numbers of people required for each job and their category--operating labor, maintenance labor, or supervisory and clerical.

The factor on payroll for administrative and general overhead is set at 0.4. The major part of this overhead is the cost of the various fringe benefits received by the workers. Due to the nature and relatively small size of an SNG plant, overhead will not be incurred for many functions encountered in a larger industrial plant, costs of which are normally included in overhead. Hence, the factor used here is smaller than that generally used for industrial plants (0.6).

With this information on capital and operating costs, the cost of SNG produced from deciduous woody material grown on Energy Plantations can be calculated for any specific combination of SNG plant capacity and local costs for boiler fuel and electricity.

These capital and operating costs are the current best estimates as of December 1974, based on the best estimates of the design and performance of the process. Many factors are not known precisely which influence significantly the performance and costs of the process, and assumed values have been used for these factors in the development of the process design. It should also be noted that certain capital charges have been omitted from the analysis, such as return and taxes. If the SNG plant is operated for the Army by a contractor, inclusion of these charges, as well as a higher overhead, would increase the total cost by 30 to 50 percent.

II.E.7. Sensitivity Analysis. The influence of these factors on the process capital and operating costs can be assessed, and realistic estimates of possible changes or improvements in these factors can be made to determine the overall potential for reducing these costs. Influential factors are listed in Table D-XV along with their presently assumed values, possible changes, and resultant changes in capital and operating costs.

TABLE D-XIII

ANNUAL OPERATING COSTS OF AN SNG PLANT

1. Plant Material: tons x $/ton
2. Ammonia: tons x $/ton
3. Boiler Fuel (fossil fuel): MMBtu X $/MMBtu
4. Electricity: kWh x $/kWh
5. Operating Labor: No. Operators x $/hr x 2080 hr.
6. Maintenance Labor: No. Maintenance People x $/hr x 2080 hr.
7. Supervision and Clerical: No. Supervisors x Avg. $/yr.
8. Administrative and General Overhead: 0.4 (Operating Labor + Maintenance Labor + Supervision)
9. Operating Supplies: 0.3 x Operating Labor
10. Maintenance Supplies: 0.02 x Total Plant Investment.
11. Replacement of Worn-Out Equipment: 0.05 x Plant Capital Cost

The cost basis for this sensitivity type of analysis is a five-train gas plant at Fort Benning processing 280,000 tons (oven-dry basis) of deciduous woody material a year. The reasons for selecting this production capacity and the associated operating costs are explained in detail in Appendix G dealing with the design of an Energy Plantation and associated gas-plant facilities at Fort Benning. The Fort Benning gas plant was selected as the cost basis for this analysis because the prices for coal and electricity, which influence the operating costs, at this location are probably more typical these days for army bases in unurbanized localities than are those for Fort Leonard Wood.

The first two factors in the table, the energy required for grinding the woody plant material to a suitable particle size and digester retention time in the digester, both influence the yield of gas which may be obtained. The present assumed values are current best estimates based on the state-of-the-art. However, specific experimental data on the digestion rate of woody plant material may show that the actual values of these factors are either more favorable or less favorable than the assumed values.

The present values of the third, fourth, and sixth factors are based upon very limited experimental data. In fact, experimental evidence exists to show that improvements in the fourth and sixth factors can be expected, but the evidence is not sufficiently precise to permit better values to be used at this time. Determining better values for these three factors, like the first two, depends upon conducting the proper experiments to obtain the appropriate precise data needed.

The fifth factor in the table is the cost of plant material, which is the biggest single item in the annual operating costs. The table shows the influence of a possible improvement in this factor on the cost of SNG produced in an Energy Plantation at Fort Benning.

TABLE D-XIV

MANPOWER REQUIREMENTS

Skill	Category	4	5	n
Manager	Supervisory & Clerical	1	1	1
Operating Foremen	"	4	4	4
Maintenance Foreman	"	1	1	1
Office Staff	"	5	5	5
Maintenance	Maintenance	14	16	3.4n
Pretreatment Operators and Helpers	Operating Labor	32	40	8n
Digester and Vacuum Filter Operators	"	16	20	4n
Gas Purification Operators and Helpers	"	8	8	8
Boiler House Operators and Helpers	"	8	8	8
Laboratory Technicians	"	2	2	2
Truck Terminal Helpers	"	2	3	0.6n
Totals		93	108	29 + 16n

If, as indicated by the sixth factor, more SNG can be obtained from the woody plant material as a result of a greater proportion of methane in the gas produced, the amount of gas needed at Fort Benning can be produced from a smaller amount of plant material processed in a four-train, rather than a five-train, plant. The required capital cost is decreased accordingly, with appropriate changes made in the cost of a four-train plant caused by the change in proportions of methane and carbon dioxide in the gas evolved from the digester.

The final entry in the table shows the combined benefits of all of the estimated improved values of all of the factors. The costs for this case were estimated by applying the improvements in the first five factors to the new cost basis indicated by the sixth factor--a four-train plant processing less woody plant material with more methane being generated than carbon dioxide. For this best case, the cost of SNG produced is \$3.51 per thousand SCF with a capital cost of \$21,462,000 to build a gas plant associated with an Energy Plantation at Fort Benning.

TABLE D-XV

INFLUENTIAL FACTORS ON CAPITAL AND OPERATING COSTS OF WOODY-MATERIAL PROCESS

Basis: Costs for five-train plant at Fort Benning

Factor	Present Value	Realistically Possible Improvement	Costs Influenced	Magnitude of Influence	Capital Cost	Cost of Gas
1. Energy for grinding	17 hp-days per dry ton	14	Electricity	-275,000		
			Replacement Costs	-2,800	$31,242,000	$4.13
2. Retention time in digesters	15 days	12	Digester Cost	-2,130,000	29,112,000	4.17
			Electricity	-34,900		
			Maintenance Supplies	-42,600		
			Replacement Costs	-106,500		
3. Solids content of feed slurry	0.12	0.15	Digester Cost	-2,130,000	28,883,000	4.14
			Heat Exchanger Cost	-70,000		
			Steeping & Mixing Tank	-159,000		
			Boiler Fuel	-70,000		
			Electricity	-34,900		
			Maintenance Supplies	-47,200		
			Replacement Costs	-118,000		
4. Solubilization of woody material	0.01	0.10	Digester Cost	-958,500	30,180,000	4.20
			Heat Exchanger Cost	-31,500		
			Steeping & Mixing Tanks	-72,000		
			Boiler Fuel	-31,500		
			Electricity	-16,500		
			Maintenance Supplies	-21,200		
			Replacement Costs	-53,100		
5. Cost of plant material	$11.26 per dry ton	$10.40	Plant Material	-241,000		
			Replacement Costs	-2,400	31,242,000	4.15
6. Split between methane and carbon dioxide in digester gas	50% methane	60%	The amount of gas needed at Fort Benning can now be produced with a four-train plant processing less material, which changes completely the basis for the calculations		25,275,000	3.68
7. Combined benefits of best values of all of the above (effect of first five factors on cost basis of sixth factor)			Digester Cost	-3,558,000	21,462,000	3.51
			Heat Exchanger Cost	-77,300		
			Steeping & Mixing Tanks	-178,000		
			Plant Material	-209,000		
			Boiler Fuel	-89,000		
			Electricity	-54,000		
			Maintenance	-76,300		
			Replacement Costs	-4,300		

III. ANAEROBIC DIGESTION OF WARM-SEASON GRASSES

III.A. Previous Experiments. Despite the accepted fact that herbaceous plant material can be readily digested anaerobically, few experiments of any type have been reported in the literature, and those which have are of the exploratory "let's-see-what-will-happen type". No quantitative process-engineering-type data are apparently available which would allow a process design to be developed for producing methane from digestion of warm-season grass plant material.

As part of a program to study solid waste management, digestion experiments have been carried out with grass clippings[9]. It was found necessary to pretreat the grass at least to the extent of grinding sufficiently to bruise the surface. However, the quantitative experiments were made with grass feed material which had been ground to a powder in a hammermill, and the feed to the digester also contained sewage sludge to the extent of fifty percent. The grass digested readily, seventy-three percent of the total material and 78.5 percent of the cellulose digesting in a retention time of thirty days at 37° centigrade. This was about the same extent of digestion as in a parallel experiment made using only sludge as the digester feed.

Although these data indicate that grass digests readily in an anaerobic environment, they are not comprehensive enough. They do not show the extent of digestibility or the methane yield as a function of pretreatment conditions, and this information is needed to design a practical digestion process for production of synthetic natural gas from warm-season grass material.

Exploratory experiments have been done on the anaerobic digestion of various water and marine plants, as well as grass, with the objective of producing synthetic natural gas[45].

Preceding page blank

Again, it was found that the surface of the plant material was resistant to biological organisms, and some sort of pretreatment was required to break down this resistance. The feed material was originally pretreated by pulverizing it in a blender, but digesters fed with this material gave poor performance.

Other pretreatments tried included contacting a slurry of the seaweed or water hyacinth with cellulase (the cellulose-hydrolyzing enzyme) for a period of time, which aided the digestion rate significantly. Also helpful was boiling the slurry with sodium hydroxide, followed by neutralization before feeding the slurry to the digester. Neither pretreatment looks promising as a practical means for pretreating feed material for an SNG production process.

In this series of experiments, ordinary grass was also used as a raw material. No pretreatment was apparently used. With the grass as the only feed material, conversion of carbon in the feed to carbon in the product methane was only 17 percent in 28 days at 48° centigrade[45]. Problems were encountered in the operation of the digester because the grass had a tendency to form a thick floating mat which did not allow the product gas to pass out of the digester.

Another series of experiments was done to investigate production of methane gas on tropical farms by anaerobic digestion of elephant grass, among other materials[46]. It was reported that the elephant grass digested readily. It was also observed that storage of the grass in a heap in the fresh state significantly reduced the obtainable gas production, that making a laceration of the stems appeared to be desirable, and that there was little difference in gas production between fresh grass used as feed material and air-dried grass. Because the objective of the work was to investigate a relatively simple uncontrolled process, the experimental conditions, operating procedures, and yield data are not applicable to our SNG production process.

It is clear from these few experiments that some sort of pretreatment is beneficial in promoting the digestibility of herbaceous plant materials. It is also clear that the rate and yield data from these experiments cannot be used as the basis for designing an economical and feasible process for producing synthetic natural gas from herbaceous plant material, such as the warm-season grasses.

For the purposes of this section of the appendix, it will be assumed that given sufficient pretreatment, herbaceous plant material will have at least the digestion rate exhibited by the kraft paper pulp powder, which is essentially pure cellulose. These experiments were described in the discussion on digestion of woody plant material, and again, it was assumed there that the plant material could be pretreated sufficiently to achieve a ninety-three percent digestibility with a retention time of fifteen days.

III.B. Composition of Coastal Bermudagrass and Theoretical Yield of Methane.
The chemical composition of plant matter from herbaceous species, such as bermudagrasses, is markedly more variable than that of woody plant materials. In herbaceous species, there is a far wider variation between species and within species than is the case for woody materials. For a particular herbaceous species, the composition of its plant matter depends to a considerable degree on the conditions under which it was grown and its age at the time of harvesting. There is also a wider variety of materials present in significant quantities in herbaceous materials than in woody plant material. In addition to carbohydrates, lignin and ash, which are the major components of woody plant material, herbaceous plant matter also contains considerable quantities of proteins and lipids. It is therefore more difficult to define a representative herbaceous material composition on the basis of which to estimate methane yields by anaerobic biological digestion and to quantitatively describe the process required.

However, selection of herbaceous materials which are suitable as raw materials for biologically producing methane is less critical than appears to be the case for woody plant material. Herbaceous materials generally decay more rapidly than woody materials and are therefore more readily subject to biological attack. This lower biological resistance is a direct result of the less rigidly organized internal structure of herbaceous plant species.

Nevertheless, in the absence of a destructive pretreatment prior to exposure to biological organisms, herbaceous plant matter from some species is much more resistant to attack than from others. The required pretreatment for the more resistant species consists primarily of destroying the outer surface of the material. The necessary pretreatment is therefore considerably less drastic than is required generally for deciduous plant matter.

Selection of a herbaceous plant species for cultivation in an Energy Plantation thus does not appear at present to be influenced much by consideration of its biological digestibility. The more important considerations are apparently its growth rate and yield, and its appropriateness to the plantation site. However, for reasons similar to those for deciduous species, a preferred herbaceous species for methane production is a perennial, rather than an annual, from which a succession of harvests can be taken per planting.

Coastal bermudagrass appears to be a preferred perennial herbaceous species because it can be grown in high yield widely throughout the warmer regions of the country where growing seasons are long and frosts are light and infrequent in winter. Data are available from the literature on its composition, at least with respect to its major components by materials class.

The data, however, show considerable variation which seems to depend on where it is grown, its age at harvest time and the extent to which it was fertilized. The amount of fixed nitrogen used in the fertilizer has a direct effect on its protein content.

A gross chemical composition for coastal bermudagrass grown in Georgia with a relatively heavy fertilization by fixed nitrogen and harvested on a twenty-four to twenty-five day cycle[47] is shown in Table D-XVI. This analysis will be used for quantitatively defining the biological process for producing methane from herbaceousplant species and for estimating the theoretical methane yield. The first four materials listed in Table D-XVI are the constituents of the cell walls, and part of the ash and hemicellulose and the fifth and sixth components are the content of the cells.

The "protein" fraction contains a mixture of a number of proteinaceous materials--hydroxyproline being the most abundant (about 20 percent of the fraction)[47]. Hydroxyproline has been taken as being generally representative of the composition of the protein fraction. However, the fraction reported also includes nonproteinaceous compounds which have nitrogen in their structures. These materials account for about twenty percent of the protein fraction. They are believed to be undigestible in an anaerobic biological process.

The ether extract contains a variety of lipids. Because no information has been found on the composition of this fraction, except that it is essentially insoluble in water, it is assumed to be largely linoleic acid esters. This fatty acid has been chosen as representative because it is a major constituent of vegetable oils.

The compounds specifically assumed to be representative of the protein and ether extractables are not likely to introduce much error in subsequent calculations. What is important, however, is to recognize the presence of

these classes of compounds because their carbon-to-oxygen ratios are very different from that of the polysaccharides. As a result, their products of biological digestion are quite different from those of the polysaccharides. In particular, on a molar basis they produce a higher methane-to-carbon dioxide ratio and fewer bacterial cells than the polysaccharides.

The general theoretical formula for anaerobic biological conversion of complex organic materials is shown in Table D-I. Application of the formulae to the digestible components of herbaceous plant material is also shown in the table.

Along with the chemical composition shown in Table D-XVI for coastal bermudagrass grown and harvested in Georgia under the stated conditions, the theoretical maximum amount of methane is also shown which can be produced from the composition by anaerobic biological digestion. The estimated theoretical maximum yield is seen to be 6.40 SCF per oven-dry pound of material charged to the digester. This is a considerably higher yield than that estimated for an "average hardwood" (5.33 SCF per pound of oven-dry wood) or an "average softwood" (4.88 SCF per oven-dry pound of softwood). The practical yield of methane which can be obtained from the coastal bermudagrass composition shown in Table D-XVI is, of course, lower than this theoretical maximum yield. The theoretical estimate does not make allowance, for instance, for the necessary continuing production of facterial cells which must occur while digestion progresses. Approximately eleven percent of the carbon in the coastal bermudagrass is used for this purpose. The theoretical yield of methane shown in the table therefore overstates the maximum practical yield by at least eleven percent.

TABLE D-XVI

THEORETICAL YIELD OF METHANE FROM COASTAL BERMUDAGRASS GROWN IN GEORGIA WITH RELATIVELY HEAVY FIXED NITROGEN FERTILIZATION AND HARVESTED ON A 24 TO 25 DAY SCHEDULE

Chemical composition of the coastal bermudagrass:

	Percent by Weight
Ash	6
Hemicellulose (pentosans)	34
Cellulose	27
Lignin	9
Protein fraction	18
Ether extract	6
	100

Cell-wall constituents	68
Cell contents	32
	100

Theoretical yield of methane from anaerobically digestible materials:

	Per Pound of Oven-Dry Matter
Methane from pentosans	2.44 SCF
Methane from cellulose	1.90
Methane from protein	1.04
Methane from ether extract	1.02
	6.40 SCF

Because, as noted earlier, the chemical composition of herbaceous plant matter varies over a wide range, only limited reliance can be placed on the theoretical methane yield estimate shown in Table D-XVI.

III.C. Pretreatment of Warm-Season Grass Material. It is apparent from the previous experimental work on biological digestion of plant material from grasses that some sort of pretreatment is beneficial in promoting digestion. As a minimum, some sort of size reduction or grinding is required. Any further pretreatment is dependent on the particular species--for example, to break up or bruise a resistant outer surface of the plant material[9,48].

The same variety of pretreatments for making woody material into a feed digestible by ruminants has been applied to various herbaceous materials for upgrading their natural digestibility by ruminants. Although these pretreatment processes, many of which involve processing with a mineral acid or an alkali, are technically successful, a process involving extensive grinding followed by steeping in steam or hot water appears to be the more economical.

The data on the effect of steeping on the chemical composition of plant materials from grasses are even less extensive than the data for woody materials. In particular, the data do not provide any information on the extent of solubilization as a function of conditions of steeping. The data, however, do indicate that steeping in steam is beneficial in promoting the biological digestibility of herbaceous materials[16]. Because of the higher natural digestibility of plant material from grasses, less steeping should be required than for woody material.

For the purposes of this appendix, it will be assumed that grass plant material can be made anaerobically digestible by grinding to a sufficiently small particle size followed by a short period of steeping at an elevated temperature. It will be assumed that the preferred pretreatment process involves steeping in hot water.

It will probably be necessary to grind the plant material, which is fed to the grinder as clippings about three inches long, to about forty mesh. The energy required for grinding is a function of moisture content--the greater the amount of moisture present, the greater the amount of energy required[26]. To minimize the energy used for grinding, the plant material should be allowed to dry in the field (field wilting) for 24-48 hours after harvesting to allow its moisture content to drop from about 300 percent moisture (dry basis) at harvesting to about 20 percent. For grinding this material to an average size of forty mesh or so in a disk attrition mill, it is assumed that about seventeen horsepower-days of energy will be required per dry ton of material. This is the same grinding energy requirement as assumed for producing SNG from deciduous plant material.

As a result of grinding, the temperature of the herbaceous material will increase from an assumed inlet temperature of 60° Fahrenheit to close to 400° Fahrenheit. Charring and catching on fire will be prevented by a steam flow into the feeder-presteamer to drive air out of the material before it is fed to the disk attrition mill, and by maintaining a steam atmosphere in the attrition mill by an open line between it and the steeping tank.

The ground material will then pass into the steeping tank where the grass particles will mix with the hot recycled filtrate and hot makeup water. It will be assumed that a half-hour of steeping in the water at 373° Fahrenheit

will be sufficient. No information is known to be available on the change in solubility of grass plant material as the result of this amount of steeping. It will be assumed here that the material which was originally soluble in the cell-contents fraction before the grass was air-dried will redissolve in the steeping tank. The estimated materials balance for this pretreatment of coastal bermudagrass is shown in Figure D-XI. The same equipment can be used for pretreating grass plant material as is recommended for woody material.

III.D. Material Balance for Anaerobic Digestion of Bermudagrass.

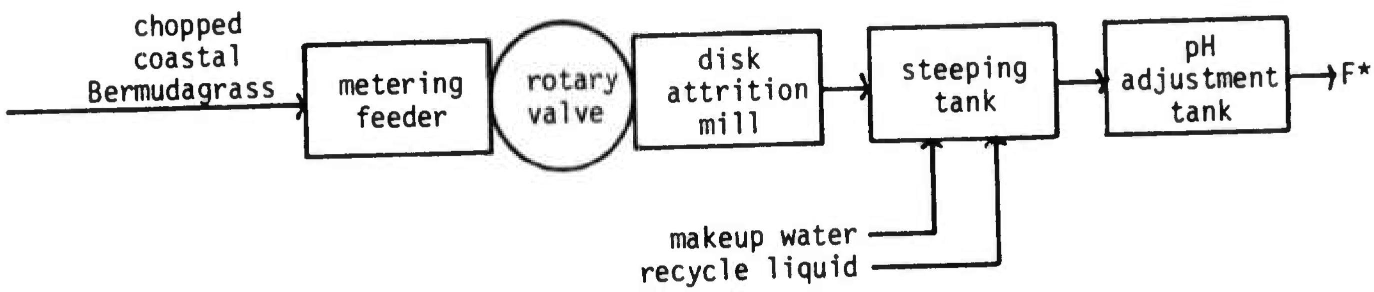
III.D.1. General. The material-balance calculations for anaerobic digestion of bermudagrass are performed in exactly the same manner as for woody plant material. The preferred pretreatment process is assumed to be to grind the air-dried material extensively into fine particles, which are then steeped in hot water. The configuration of equipment is the same, and the two mixing tanks--the steeping tank and the pH-adjustment tank--have the same functions.

Again, the solids content of the feed slurry to the digesters should be at the highest level consistent with slurry pumpability, and this maximum, in the absence of experimental data, is assumed here to be twelve percent.

Although anaerobic digestion data are available in the literature for digestion of grass, the data which are most applicable to the digestion of bermudagrass are the data on kraft paper pulp powder[10]. The literature data on digestion of grass were obtained on grass clippings which had been ground to an unknown degree and not steeped, and the microorganism population was not maintained at peak efficiency[9]. Other experiments on herbaceous materials have been done and are reported in the literature, but the results from these mainly exploratory experiments are not suitable for the purposes of this appendix.

FIGURE D-XI

PRETREATMENT OF BERMUDAGRASS PLANT MATERIAL FLOW DIAGRAM AND ESTIMATED MATERIALS BALANCE



*F = Feed to anaerobic digesters

MATERIALS BALANCE

Basis: 1 ton oven-dry Coastal Bermudagrass

	FLOWS (tons)				
Materials	Chopped Grass	Makeup Water	Recycled Filtrate	Added N	Feed to Digester
Ash	0.06				0.06
Pentosans	0.34				0.34
Cellulose	0.27				0.27
Lignin	0.09				0.09
Protein Fraction:					
Proteins	0.144				0.144
Inerts	0.036				0.036
Lipids	0.06				0.06
Recycled Inerts			?		?
Water or Steam	0.20	?	?		0.20 + ?
Nitrogen				?	?

Bermudagrass should be easier to digest than woody plant materials, but the difference is most likely to be reflected mainly in the degree of pretreatment necessary. It is definitely beneficial to pretreat grass materials, but less pretreatment will probably be required than for woody materials in order to bring grass material to the same degree of digestibility as woody material. In other words, once grass and woody materials have been pretreated, albeit to different degrees, the resulting raw-material feed for the digester should be essentially the same in both cases, and the same digestion rate should apply. The fraction of refractory material remaining after digestion which is difficult to digest is undoubtedly different for feed prepared from grass material, but no data to our knowledge are available to estimate this quantity.

For these reasons, the data on kraft paper pulp powder are assumed to be applicable to the proposed process for producing methane from bermudagrass and other grasses as well as from woody materials. It is assumed for the purposes of this appendix that 93 percent of the cellulose, hemicellulose, proteins, and lipids in the coastal bermudagrass will be digested to methane with the residual material assumed to be cellulose because it is the slowest to digest.

Because more of the grass material should be soluble in water than in the case of the woody material, the digester loading in pounds of substrate per cubic foot of digester liquid per day will be higher even though the twelve percent limit on suspended-solids content in the feed slurry is maintained.

The yields of gas and bacterial cell material produced from the digestion are calculated separately for each digestible component according to model reaction equations and then summed together. The model reaction equations used for the digestion of grass materials are shown in Figure D-XII.

FIGURE D-XI

MODEL REACTION EQUATIONS FOR ANAEROBIC DIGESTION OF BERMUDAGRASS

1. Fermentation of Pentosan:

$C_5(H_2O)_4$ +	N +	$H_2O \longrightarrow$	Bacterial Cells +	CH_4 +	CO_2
1 lb	0.0132	0.088	0.106	0.265	0.730

2. Fermentation of Cellulose:

$C_6(H_2O)_5$ +	N +	$H_2O \longrightarrow$	Bacterial Cells +	CH_4 +	CO_2
1 lb	0.0129	0.065	0.104	0.260	0.714

3. Fermentation of Protein (Hydroxyproline):

$C_5H_9NO_3$ +	$H_2O \longrightarrow$	Bacterial Cells +	CH_4 +	CO_2 +	N
1 lb	0.223	0.066	0.282	0.776	0.099

4. Fermentation of Lipid (Linoleic Acid):

$C_{18}H_{32}O_2$ +	N +	$H_2O \longrightarrow$	Bacterial Cells +	CH_4 +	CO_2
1 lb	0.0068	0.566	0.055	0.687	0.831

The growth yield coefficients (mass of bacteria formed per unit mass of substrate consumed) for pentosan and cellulose are the same as those assumed for the digestion of woody plant materials. The coefficients for protein and lipid were obtained from theoretical calculations shown in the literature[29], but these values are only approximations.

The material-balance calculations for carbon dioxide, bicarbonate, nitrogen, and amount of alkali needed to maintain the pH are all done for the process for coastal bermudagrass in exactly the same manner and with the same assumptions as for the process for woody material.

Similarly, the same assumptions are made for the performance of the vacuum filter. It is assumed that the solids capture efficiency of the filter is ninety percent, and the practical cake solids content which can be obtained is twenty-five percent. A solids yield of six pounds of solids per square foot of filter area per hour is assumed.

The complete material-balance estimations are shown in Figure D-XIII. It will be noted it is estimated that about 10,800 SCF of methane are expected to be produced from an oven-dry ton of bermudagrass, whereas only about 8,900 SCF are estimated from a similar weight of woody material.

<u>III.D.2. The Steeping and pH-Adjustment Tanks</u>. Calculations of the water to be added to the steeping tank to make up the feed slurry involves the recycled filtrate from the vacuum filter. Because the solids content of this stream is not known for the first calculations, an approximation must be used, and it was assumed at first that the solids content was 0.5%. After the first calculations, a revised number can be used for subsequent calculations. The recycle stream will be in balance when the assumed recycled solid material is equal to the solids in the vacuum-filter filtrate which is recycled to

the steeping tank. The final calculations are described here. The nitrogen input N into the pH-adjustment tank is assumed to be negligible for the purposes of this calculation.

Solids in ground grass (from Figure D-XI): 0.68 tons
Water and solubles in ground grass (from Figure D-XI): 0.52 tons
Suspended solids in recycled filtrate and makeup water added to the mixing tank: $0.0074\ W_r$ tons,
where W_r is the total tons of water added to the steeping tank from makeup water and the recycled filtrate.
Calculate amount of water W_r needed to make up slurry of twelve percent concentration in suspended solids:

$$0.12 = \frac{0.68 + 0.0074\ W_r}{0.68 + 0.0074W_r + 0.52 + W_r}$$

$$W_r = 4.723 \text{ tons}$$

Total weight into digester: $0.68 + 0.52 + 0.035 + 4.723 = 5.958$ tons

Density of slurry (water @ 140°F + solids @ sp. gr. 1.2): 62.4 lb/ft^3

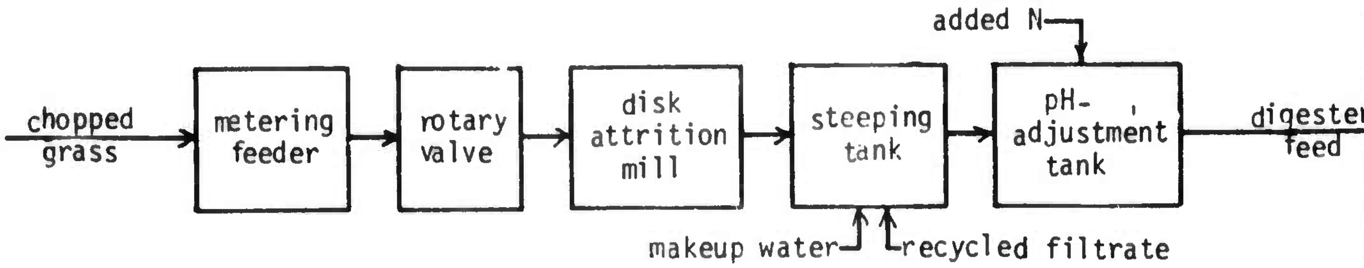
Volume of feed slurry: $\frac{5.958 \times 2000}{62.4} = 191\ ft^3$

Digestible-material concentration in feed to digester: assume the biodigestible materials in the grass are cellulose, pentosans, proteins, and lipids. Their total weight is 0.814 tons per ton of oven-dry grass:

$$\frac{0.814 \times 2000}{191} = 8.52\ lb/ft^3$$

FIGURE D-XIII

MATERIAL BALANCE FOR METHANE PRODUCTION BY ANAEROBIC DIGESTION OF BERMUGRASS



MATERIAL BALANCE

Basis: 1 ton oven-dry coastal bermudagrass

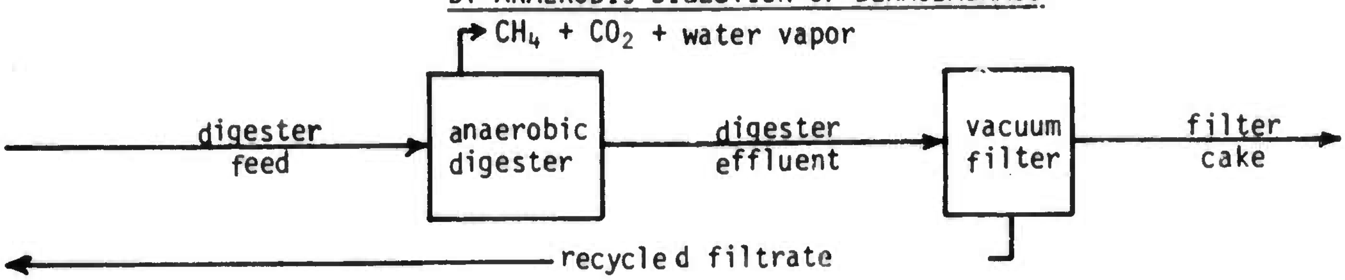
------------------------------FLOWS (tons)------------------------------

MATERIALS	Chopped Grass	Makeup Water	Recycled Filtrate	Added N	Digester Feed
Suspended Solids:					
Lignin	0.090	-	-	-	0.090
Ash and other inerts	0.096	-	-	-	0.096
Cellulose	0.270	-	-	-	0.270
Pentosans	0.340	-	-	-	0.340
Bacterial Cells	-	-	-	-	-
Recycled Inerts	-	-	0.035	-	0.035
Water or Steam	0.200	0.971	3.752	-	4.923
Dissolved Materials:					
Proteins	0.144	-	-	-	0.144
Lipids	0.060	-	-	-	0.060
Acetic Acid	-	-	-	-	-
Carbon Dioxide	-	-	0.0011	-	0.0011
Bicarbonate	-	-	0.0076	-	0.0076
Nitrogen	-	-	0.0263	-	0.0263
Gas:					
Water Vapor	-	-	-	-	-
Methane	-	-	-	-	-
Carbon Dioxide	-	-	-	-	-
Total Weight:	1.200	0.971	3.822	-	5.993
Volumes:					
Liquid	-	-	-	-	191 ft^3
Gas (total)	-	-	-	-	-
Methane (dry)	-	-	-	-	-

FIGURE D-XIII (continued)

MATERIAL BALANCE FOR METHANE PRODUCTION

BY ANAEROBIC DIGESTION OF BERMUDAGRASS



MATERIAL BALANCE

Basis: 1 ton oven-dry coastal bermudagrass

--------------------------------FLOWS (tons)--------------------------------

MATERIALS	Digester Feed	Digester Effluent	Filter Cake	Recycled Filtrate
Suspended Solids:				
Lignin	0.090	0.090	0.081	0.009
Ash and other inerts	0.096	0.096	0.086	0.010
Cellulose	0.270	0.057	0.051	0.006
Pentosans	0.340	-	-	-
Bacterial Cells	-	0.071	0.064	0.007
Recycled Inerts	0.035	0.035	0.032	0.003
Water or Steam	4.923	4.694	0.942	3.752
Dissolved Materials:				
Proteins	0.144	-	-	-
Lipids	0.060	-	-	-
Acetic Acid	-	-	-	-
Carbon Dioxide	0.0011	0.0014	0.0003	0.0011
Bicarbonate	0.0076	0.0100	0.0024	0.0076
Nitrogen	0.0263	0.0329	0.0066	0.0263
Gas:				
Water Vapor	-	0.119	-	-
Methane	-	0.227	-	-
Carbon Dioxide	-	0.562	-	-
Total Weight:	5.993	5.995	1.265	3.822
Volumes:				
Liquid	191 ft^3	163 ft^3	39 ft^3	124 ft^3
Gas (total)	-	25,400 SCF	-	-
Methane (dry)	-	10,800 SCF	-	-

III.D.3. Anaerobic Digester:

Digester loading: $\frac{8.52}{15} = 0.568 \frac{lb}{ft^3}$ of digester liquid-day

Total substrate in: 0.814 tons

Substrate digested: 0.814 x 0.93 = 0.757

Substrate left (cellulose): 0.057 tons

The production of methane, carbon dioxide, and bacterial cells is calculated according to the model reaction equations in Figure D-XII. The equations are also used to calculate the amount of water entering into the reactions and the amount of nitrogen used by the bacteria. The digester material balance is shown in Figure D-XIII.

Percent suspended solids in digester effluent:

Total suspended solids out = 0.349 tons

Total weight out = 5.04 (neglecting CO_2, and HCO_3^- and fixed nitrogen) tons

Percent suspended solids = $\frac{0.349 \times 100}{5.04} = 6.9\%$

The specific gravity of this mixture will be approximately 1.01. The volume of liquid effluent out was calculated with this assumption .

The digester gas is assumed to be saturated with water vapor at atmospheric pressure at 140°F, and the digester effluent is assumed to be saturated with carbon dioxide. The net amount of carbon dioxide which leaves the digester in the effluent, either as dissolved carbon dioxide or bicarbonate, is calculated and subtracted from the carbon dioxide produced.

These calculations of the carbon dioxide balance and the amount dissolved depend on the amounts of dissolved carbon dioxide and bicarbonate in the filtrate recycled to the steeping tank. This latter quantity depends in turn on the performance of the vacuum filter.

III.D.4. Vacuum Filter:

The material balance for the vacuum filter is shown in Figure D-XIII. It should be noted that the filter, under the assumed conditions, does not yield quite enough filtrate for the required amount of recycle. Some fresh water will have to be used, or the vacuum filter will have to operate under different conditions to obtain more filtrate.

The volume of filtrate shown in Figure D-XIII is calculated using the density of water at 140°F, which is 61.4 pounds per cubic foot.

III.D.5. Calculation of Carbon Dioxide Balance:

Calculation of dissolved carbon dioxide and bicarbonate:

$$\text{mole fraction } CO_2 \text{ in solution} = \frac{\text{partial pressure } CO_2}{\text{Henry's Law constant}}$$

$$xCO_2 = \frac{0.380 \text{ atm}}{3410 \text{ (@ 140°F) atm}}$$

$$= 1.12 \times 10^{-4}$$

Concentration of CO_2 in solution = 6.22×10^{-3} gmoles/liter

$$(HCO_3^-) = \frac{(CO_2)\ 5.19 \times 10^{-7} \text{ (@140°F)}}{(H+)}$$

Assume digester is maintained at pH of 7:

$$(HCO_3^-) = \frac{6.22 \times 10^{-3} \times 5.19 \times 10^{-7}}{10^{-7}}$$

$$= 0.0323 \text{ gmoles/liter}$$

Volume of recycled filtrate: 124 ft^3

Dissolved CO_2 in filtrate: $\frac{0.017 \times 124}{2000} = 0.0011$ tons

Bicarbonate in filtrate: $\frac{0.123 \times 124}{2000} = 0.0076$ tons

Dissolved CO_2 in digester effluent: $\frac{0.017 \times 163}{2000} = 0.0014$ tons

Bicarbonate in digester effluent: $\frac{0.123 \times 163}{2000} = 0.0100$ tons

CO_2 produced that is solubilized: $\frac{(0.0100 - 0.0076)\ 44}{61} + (0.0014 - 0.0011)$

$$= 0.002 \text{ tons}$$

Amount of alkali that must be added to system to maintain pH:

$$\frac{(0.0100 - 0.0076)}{61} = 3.9 \times 10^{-5} \text{ ton equivalents}$$

III.D.6. Nitrogen and Phosphorus Balance Calculations:

Carbon in digestible substrate:

Cellulose	0.120
Pentosans	0.155
Proteins	0.066
Lipids	0.046
	0.387 tons carbon

Necessary fixed nitrogen (as N) in feed: $\frac{0.387}{20}$ = 0.0194 tons

Fixed nitrogen in bacterial cells: 0.124 x 0.071 = 0.0088 tons

Fixed nitrogen in effluent: 0.0194 - 0.0088 = 0.0106 tons

Fixed nitrogen in recycled filtrate: 0.0106 x $\frac{3.752}{4.694}$ = 0.0085 tons

Fixed nitrogen which must be added to mixing tank: 0.00194 - 0.0085 = 0.0109 tons

Fixed nitrogen in proteins in grass feed: 0.0154 tons

The nitrogen in the proteinaceous material in the grass feed apparently is more than sufficient to make up the net amount which must be added to the system to maintain an optimum environment for the microorganisms in the digester. No other source of nitrogen is apparently needed.

Phosphorous must also be provided. The nitrogen-to-phosphorous ratio must be about five. The amount of phosphorus used in making bacterial cells is not known. The assumption is made that the same proportions apply to phosphorus as nitrogen; that is, the same proportion is recycled. Therefore, the amount of phosphorus which must be added to the mixing tank is:

Amount phosphorus to be added (as P): $\frac{0.0109}{5}$ = 0.002 tons

III.E. Process Design and Costs.

III.E.1. General. The design of the process for producing methane from warm-season grasses is very similar to the woody-material process design. It is assumed that the preferred pretreatment process for woody material, which involved extensive grinding followed by steeping in hot water, is suitable also for pretreating warm-season grasses. Because grass initially is more susceptible to biological attack, the pretreatment perhaps does not have to be as extensive; grinding may consume less energy, and steeping

can be done at a lower temperature, for example. However, these factors influence operating costs, not capital costs. The capital costs for a processing train based on warm-season grass should be very similar to that for a plant producing methane from woody material.

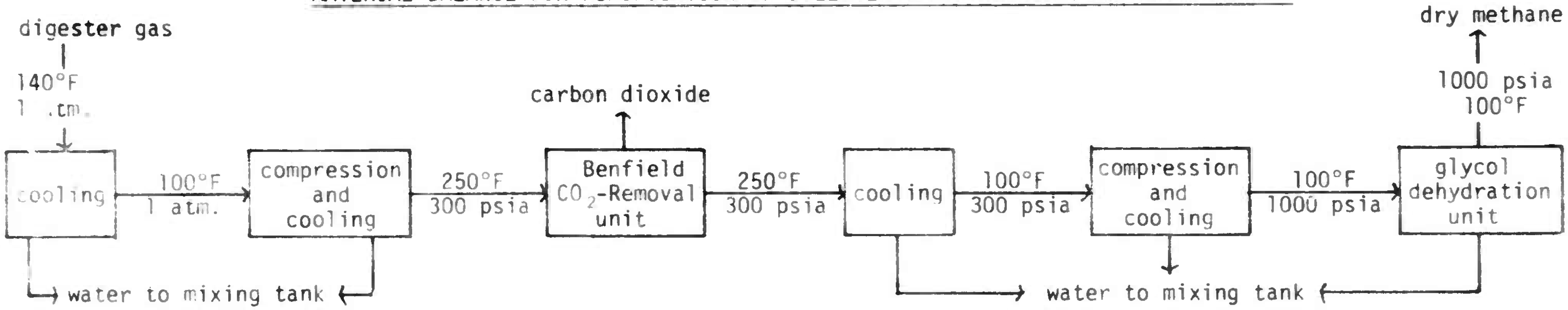
The capacity of a processing train for woody material is basically set by the capacity of the disk attrition mill, whose capacity is determined in terms of a volumetric feed rate. Because the bulk density of grass is intrinsically lower than that of deciduous woody material, the mass feed rate of grass to the grinder will be lower, and the capacity of the grinder will be less. The capacity of the grinder can be maintained at the assumed 200 tons (oven-dry basis) per day if the grass has been crushed to increase its bulk density, and this can be done very easily with a "nip", which squeeze and crush the grassy material as it is fed between them. It is assumed that this operation is done and that the grinder then has a capacity of 200 dry tons per day.

No data appear to be available on the energy required for grinding the bermudagrass to a suitable particle size to achieve a practical digestion rate. However, it appears that grinding bermudagrass will take about as much energy as grinding deciduous woody material to the same particle size. Therefore, it is assumed that grinding the bermudagrass will require seventeen horsepower-days per ton (oven-dry basis) of material.

The same process train for gas purification is used in the bermudagrass process as in the woody-material process. The material balance for gas purification is shown in Figure D-XIV.

FIGURE D-XIV

MATERIAL BALANCE FOR PURIFICATION OF DIGESTER GAS PRODUCED FROM BERMUDAGRASS



MATERIAL BALANCE

Basis: 1 ton (oven-dry basis) coastal bermudagrass

	FLOWS (tons)		
	Methane	Carbon Dioxide	Water
Digester Gas	0.227	0.562	0.119
Water from Cooling	-	-	0.086
Gas to Compression	0.227	0.562	0.033
Water from Cooling	-	-	0.026
Gas to Benfield Unit	0.227	0.562	0.007
Carbon Dioxide Off-gas	-	0.556	?
Methane to Cooling	0.227	0.006	0.029
Water from Cooling	-	-	0.0282
Methane to Compression	0.227	0.006	8.2×10^{-4}
Water from Cooling	-	-	5.8×10^{-4}
Methane to Dehydration	0.227	0.006	2.4×10^{-4}
Water from Dehydration	-	-	2.1×10^{-4}
Product Gas (10,800 SCF)	0.227	0.006	2.7×10^{-5}

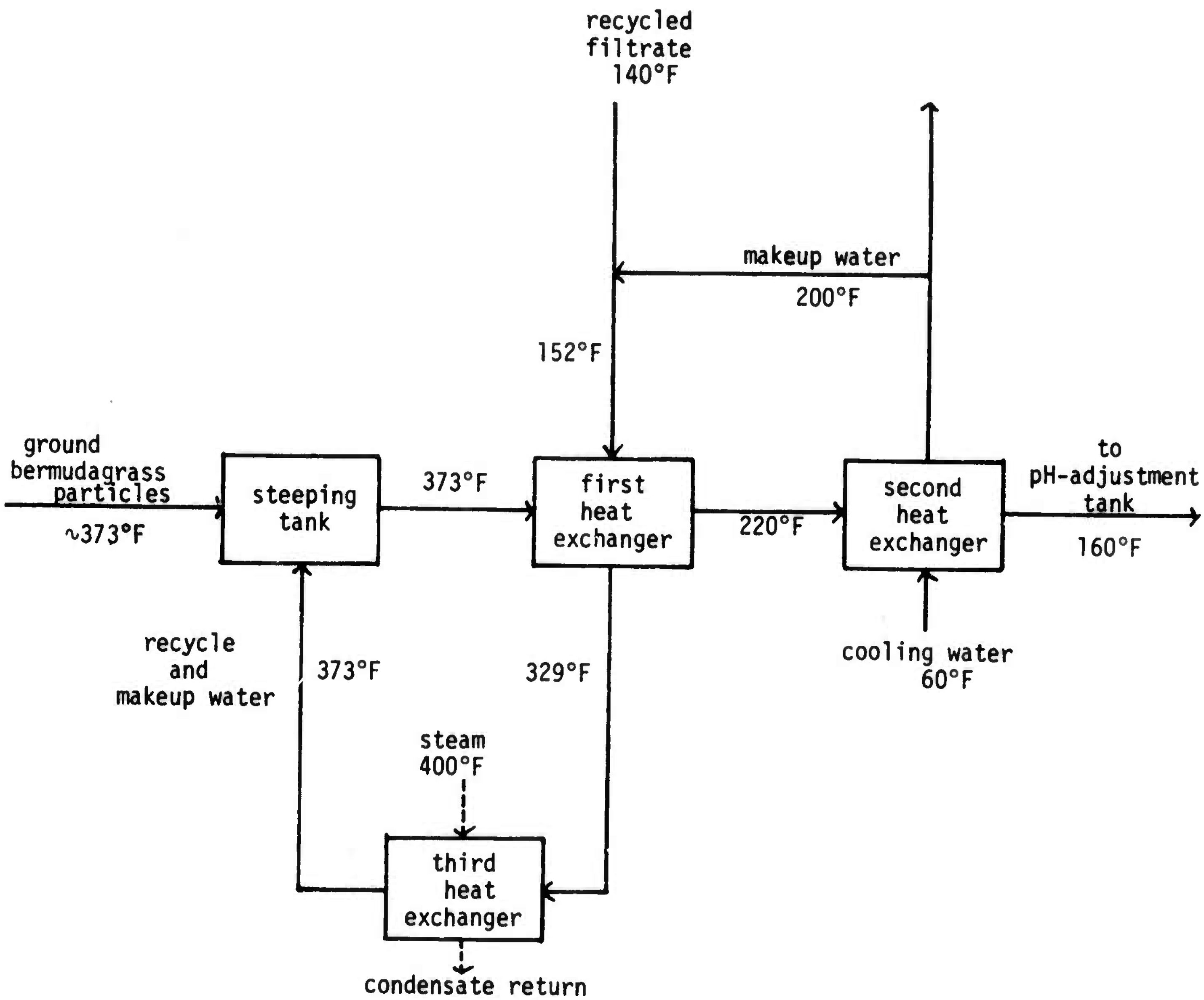
The estimated energy balance and capital requirements for a plant processing 200 tons (oven-dry basis) per day of coastal bermudagrass, which are presented in the next sections, can be estimated from the information on major pieces of equipment presented in section II.E.2 on process design for SNG production from deciduous woody material. There are certain changes in the size and cost of some of the equipment, for example the digester, because of the differences between the two processes for woody materials and bermudagrass, and these are noted in the discussion. The process for producing SNG from bermudagrass is designed for producing pipeline-quality SNG, for the same reasons as discussed for the process for woody materials.

<u>III.E.2. Energy Balance for the Entire SNG Process</u>. The energy requirements for the equipment in the pretreatment and digestion parts of the process should be essentially the same as for the equipment in the woody-material process because the same amount of material is involved. In those places where a different amount of material is involved, the energy requirement can easily be scaled from the corresponding energy need in the woody-material process.

The design for the heat exchange between the entering and exiting flows in the steeping tank is the same as the design for the woody-material process except that the temperatures are slightly different. For example, the flow to the pH-adjustment tank must have a temperature of 160°F, rather than 152°F, to provide enough heat to the digester to allow for heat losses and vaporization of water which takes place in the digester. The heat-exchange design is shown in Figure D-XV. The heat exchangers will be somewhat smaller than the ones in the woody-material process, but the difference in cost will not be large so that the same costs for these three exchangers are assumed.

FIGURE D-XV

HEAT EXCHANGE AROUND THE STEEPING TANK



Under the conditions shown in Figure D-XV, about 3.47×10^6 Btu per hour must be added to the recycle-plus-makeup water stream entering the steeping tank per processing train. To provide this heat by condensation of 400°F saturated steam requires 2.10 tons of steam per hour.

The energy requirement for one processing train is shown in Figure D-XVI. The energy requirements for the steeping tank, mixing tank, and digesters have been calculated by scaling down, according to volumes involved, the corresponding energy needs in the woody-material process. The energy requirements for the steps in the gas-purification part of the process were determined by scaling up, according to the gas volume handled, the corresponding energy needs in the woody-material process.

A total of 5,116 horsepower is required for shaft power, and the steam requirements are 2.13 tons per hour of 400°F steam and 4.41 tons per hour of 300°F steam. About 552 kilowatts of electricity or 740 horsepower of shaft power can be generated from this steam before it is used as process steam. A proposed system for doing this is shown in the figure. This amount of power would be sufficient for all equipment except the disk attrition mill and the digester-gas compressor.

The calculation of the overall energy balance for the entire process is shown in Table D-XVII. The assumption has been used again that the process steam boiler is fired with fossil fuel. The energy efficiency as the energy output divided by the energy input is about 60 percent. The energy efficiency as energy output divided by the input of conventional energy is about 173 percent.

<u>III.E.3. Total Capital and Operating Costs</u>. The estimated total capital cost for the entire process is summarized in Table D-XVIII. As compared with the cost for the woody-material process, some of the costs have been

TABLE D-XVII

ENERGY BALANCE

Basis: 1 hour

ENERGY INPUTS:

Energy in grass processed -

$$8.33\ \frac{\text{tons}}{\text{hr}} \times 2000\ \frac{\text{lb}}{\text{ton}} \times 6000\ \frac{\text{Btu}}{\text{lb}} = 99.96 \times 10^6\ \frac{\text{Btu}}{\text{hr}}$$

Energy used by boiler -

Energy in steam -- Energy in condensate

$$\frac{17.13 \times 10^6 - 3.98 \times 10^6}{\underset{\text{Boiler efficiency}}{0.65}} = 20.23 \times 10^6\ \frac{\text{Btu}}{\text{hr}}$$

Primary fuel used by utility to generate electricity -

5,116	total horsepower
- 740	obtained with process steam
4,376	horsepower from utility electricity

$$4{,}376\ \text{hp} \times \frac{1\ \text{kW}}{1.341\ \text{hp}} \times 9{,}300\ \frac{\text{Btu}}{\text{kWh}} = 30.35 \times 10^6\ \frac{\text{Btu}}{\text{hr}}$$

ENERGY OUTPUT:

Energy in methane -

$$90{,}000\ \frac{\text{SCF}}{\text{hr}} \times 1000\ \frac{\text{Btu}}{\text{SCF}} = 90.0 \times 10^6\ \frac{\text{Btu}}{\text{hr}}$$

ENERGY EFFICIENCY:

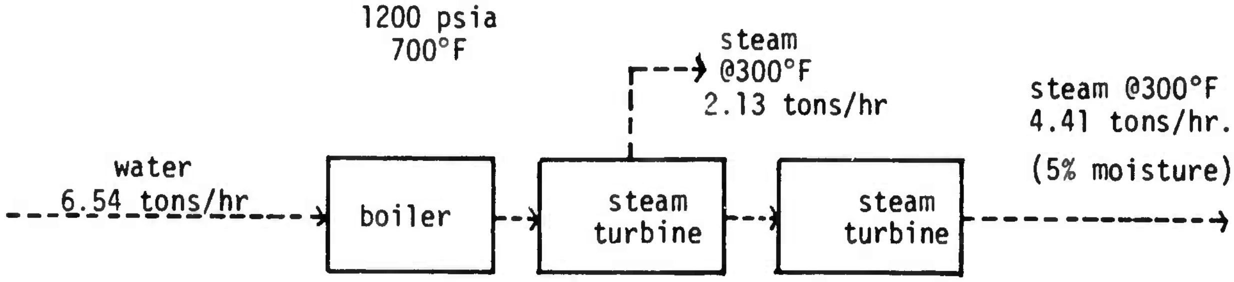
$$\frac{90.0 \times 10^6}{150.5 \times 10^6} \times 100 = 60\%$$

FIGURE D-XVI

ENERGY REQUIREMENTS FOR DIGESTION OF BERMUDAGRASS

Basis: One hour's operation of one processing train with capacity of 200 tons (oven-dry basis) per day.

Steam Generation



Electrical Generation: 552 kW (740 hp)

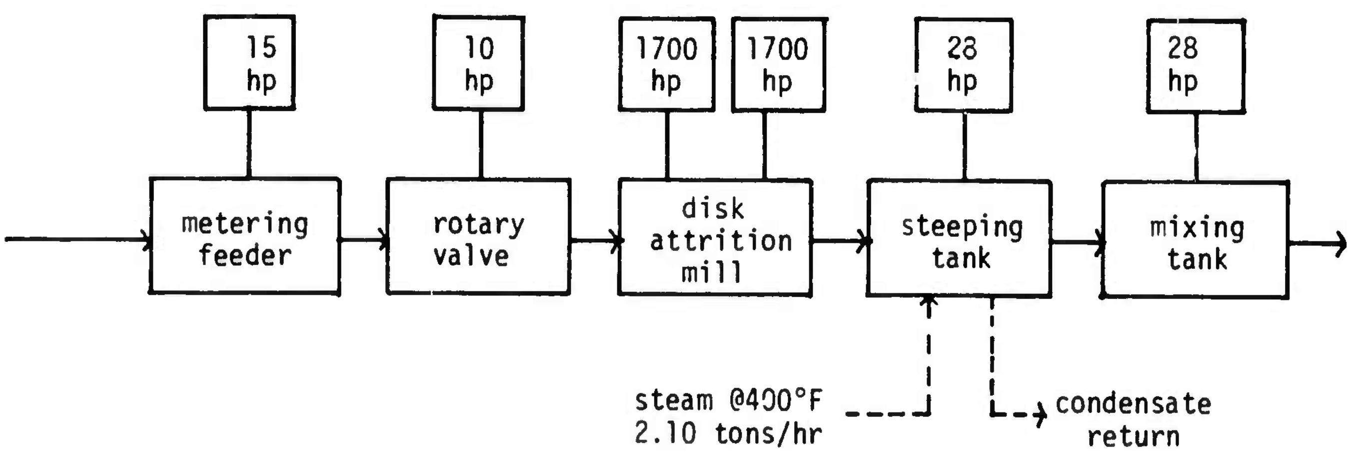
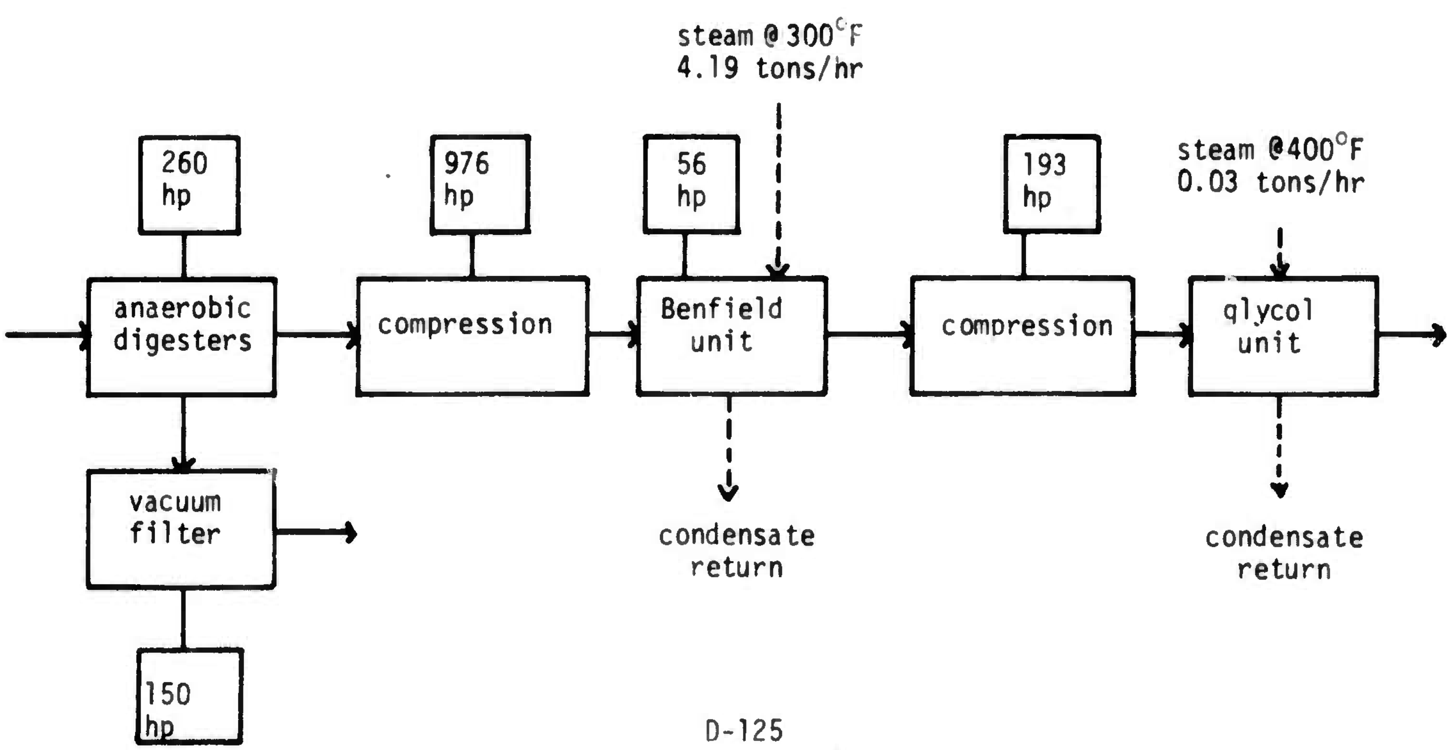


FIGURE D-XVI (continued)

ENERGY REQUIREMENTS FOR DIGESTION OF BERMUDAGRASS

Basis: One hour's operation of one processing train with capacity of 200 tons (oven-dry basis) per day.



adjusted downward with appropriate capacity exponents--such as the tanks--or upward--such as the compressors, carbon dioxide removal unit, and dehydration unit. The estimated costs for a four-train plant and an n-train plant are shown in Table D-XVIII. The total installed cost estimated for a four-train plant is about $22.3 million for a capacity of 8.64 million SCF per day, or about $2.58 per daily SCF of SNG production capacity.

The operating-cost factors for the bermudagrass process are the same as outlined for the woody-material process (see Table D-XIII) except that ammonia does not have to be provided. It is anticipated that the proteinaceous material in the grass will provide all the fixed nitrogen needed for the digestion process. The manpower requirements for a bermudagrass plant are the same as for a woody-material plant using the same amount of raw material.

The largest single item of operating expense is the cost of the plant raw material. This cost is not strongly dependent on location where it is feasible to grow a warm-season grass in an Energy Plantation. A warm-season grass was considered for the Energy Plantation at Fort Benning but was not selected because the growing season is not long enough (see section III. in Appendix G). The costs involved in growing a warm-season grass have been worked out for consideration for those Army bases which might have a suitable climate. These costs are shown in Table D-XIX for plantations of two different sizes and for two different possible yields per acre per year. The cost of the plant material produced varies between $8.49 and $9.02 per dry ton.

The estimated costs involved in producing SNG from warm-season grass material in an amount equivalent to Fort Benning's needs, as an example, are shown in Table D-XX. The estimated cost of the SNG is $2.92 per thousand standard

TABLE D-XVIII

TOTAL ESTIMATED CAPITAL COSTS FOR SYSTEMS PRODUCING SNG FROM BERMUDAGRASS

	Number of Pretreatment-Anaerobic Digestion Trains	
	4	n
Raw Material, tons (oven-dry basis) per day	800	200n
SNG Capacity, 10^6 SCF per day	8.64	2.16n
Equipment and Estimated Installed Cost		
Nips Metering Feeders Rotary Valves Disk Attrition Mills	\$ 5,920,000	\$1,480,000n
Steeping Tanks	640,000	160,000n
Heat Exchangers	360,000	90,000n
pH-adjustment Tanks	296,000	74,000n
Anaerobic Digesters	5,480,000	1,370,000n
Vacuum Filters	3,040,000	760,000n
Heat Exchangers	43,000	$17{,}500n^{0.65}$
Compressors	2,478,000	$795{,}000n^{0.82}$
Benfield Unit	982,000	$372{,}000n^{0.7}$
Heat Exchangers	52,000	$21{,}000n^{0.65}$
Compressors	736,000	$236{,}000n^{0.82}$
Glycol Dehydration Unit	136,000	$59{,}000n^{0.6}$
Steam Generation and Distribution	2,100,000	$693{,}000n^{0.8}$
Estimated Installed Cost:	\$22,263,000	The sum of the entries above
Estimated Installed cost per Daily SCF of SNG Production Capacity:	\$2.58	

cubic feet, assuming the grass material delivered to the SNG production facility costs \$8.65 per ton (oven-dry basis). This cost is considerably less than the estimated cost of SNG at Fort Benning from deciduous woody material. The primary reason why gas from grass costs less than gas from wood is that more gas can be made from the same quantity of dry material. The plant raw material costs less, too, in the case of grass.

<u>III.E.4. Sensitivity Analysis</u>. The same influential factors apply to the capital and operating cost estimates for the bermudagrass process as for the woody-material process. The influence of reaslistically possible improvements in these factors is shown in Table D-XXI. If the benefits of all of the potential improvements can be obtained, the estimated capital cost is reduced from about \$22.3 million to about \$15.1 million, and the estimated cost of SNG from \$2.92 to \$2.36 per thousand standard cubic feet.

TABLE D-XIX

CAPITAL AND OPERATING COSTS FOR PRODUCING
WARM-SEASON GRASSES ON AN ENERGY PLANTATION

	Annual Production			
	200,000 O.D. Tons		240,000 O.D. Tons	
Annual Yield	8 tons/acre	10 tons/acre	8 tons/acre	10 tons/acre
Capital Costs				
Equipment	$1,901,000	$1,881,000	$2,203,000	$2,183,000
Plantation Establishment	3,229,000	2,676,000	3,875,000	3,211,000
Total	$5,130,000	$4,557,000	$6,078,000	$5,394,000
Annual Operating Costs				
Labor	858,000	839,000	1,002,000	981,000
Supplies	524,000	490,000	622,000	583,000
Total	$1,382,000	$1,329,000	$1,624,000	$1,564,000
Replacement-Equipment	325,000	324,000	378,000	377,000
Plantation Maintenance	97,000	80,000	116,000	96,000
Total Annual Costs	$1,804,000	$1,733,000	$2,118,000	$2,037,000
Cost of Grass - $ per dry ton	9.02	8.66	8.82	8.49

TABLE D-XX

ESTIMATED COST OF PRODUCING SNG FROM BERMUDAGRASS ON A SCALE EQUIVALENT TO THE REQUIREMENTS OF FORT BENNING

Number of Pretreatment-Anaerobic Digestion Trains: 4

Annual Production of SNG: 2.59×10^9 SCF

Estimated Annual Operating Costs:	
Plant Material (240,000 tons x $8.66/O.D. ton)	$2,078,000
Boiler Fuel (583,000 MMBtu x $0.891/MMBtu)	519,000
Electricity (9.40×10^7 kWhr x $0.0183/kWhr)	1,720,000
Operating Labor (68 x $5/hr x 2080 hr)	707,000
Maintenance Labor (14 x $5/hr x 2080 hr)	146,000
Supervision and Clerical (11 x $14,000/yr)	155,000
Administrative and General Overhead [0.4 (707,000 + 146,000 + 155,000)]	403,000
Operating Supplies (0.3 x 707,000)	212,000
Maintenance Supplies (0.02 x $22,263,000)	445,000
Total Estimated Operating Costs	$6,385,000
Replacement Costs ($23,540,000/20 yr)	$1,177,000
Total Costs	$7,562,000
Cost of SNG ($7,562,000/$2.59 \times 10^6$ MSCF produced)	$2.92/MSCF

Preceding page blank

TABLE D-XXI

INFLUENTIAL FACTORS ON CAPITAL AND OPERATING COSTS OF AN SNG PRODUCTION FACILITY USING BERMUDAGRASS

Basis: costs for a facility having four pretreatment-anaerobic digestion trains

Factor	Present Value	Realistically Possible Improvement	Costs Influenced	Magnitude of Influence	Capital Cost	Cost of Gas
1. Energy for grinding	17 hp-days per dry ton	14	Electricity	-236,000	$\$22.3 \times 10^6$	\$2.83
			Replacement Costs	-2,400		
2. Retention time in digesters	15 days	12	Digester Cost	-1,096,000	21.2×10^6	2.88
			Electricity	-31,400		
			Maintenance Supplies	-21,900		
			Replacement Costs	-55,300		
3. Solids content of feed slurry	12%	15%	Digester Cost	-1,096,000	21.0×10^6	2.85
			Heat Exchanger Cost	-56,000		
			Steeping & Mixing Tanks	-106,000		
			Boiler Fuel	-54,500		
			Electricity	-31,400		
			Maintenance Supplies	-25,200		
			Replacement Costs	-64,000		
4. Solubilization of grass plant material	20.4%	28.4%	Digester Cost	-493,000	21.7×10^6	2.89
			Heat Exchanger Cost	-25,200		
			Steeping & Mixing Tanks	-46,000		
			Boiler Fuel	-24,500		
			Electricity	-14,300		
			Maintenance Supplies	-11,300		
			Replacement Costs	-28,700		
5. Split between methane and carbon dioxide in digester gas	50% methane	60%	The amount of gas can now be produced with a three-train plant processing less material which changes completely the basis for the calculation.		17.0×10^6	2.54
6. Combined benefits of best values of all of the above (effect of first four factors on cost basis of fifth factor)			Digester Cost	-1,716,000	15.1×10^6	2.36
			Heat Exchanger Cost	-57,900		
			Steeping & Mixing Tanks	-110,000		
			Boiler Fuel	-65,000		
			Electricity	-281,000		
			Maintenance Supplies	-37,000		
			Replacement Costs	-98,000		

Preceding page blank

IV. REFERENCE LIST

1. Perry L. McCarty; Public Works; p. 107, September 1964; p. 123, October 1964; p. 91, November 1964; p. 95, December 1964.

2. Anaerobic Sludge Digestion Manual, Journal Water Pollution Control Federation, p. 1683, October 1966; November 1966; December 1966.

3. Frederick G. Pohland, Engineering Bulletin of Purdue University, Vol. XLVI, No. 5, September 1962.

4. A. M. Buswell, Sewage and Industrial Wastes, p. 717, June 1957.

5. Richard R. Dague, Journal Water Pollution Control Federation, p. 2021, December 1968.

6. F. A. Sanders and Don E. Bloodgood, Journal Water Pollution Control Federation, P. 1741, December 1965.

7. Perry L. McCarty and Ross E. McKinney, Journal Water Pollution Control Federation, p. 399, April 1961.

8. Private communication between Malcolm D. Fraser, InterTechnology Corporation, and Ross E. McKinney, University of Kansas, July 16, 1974.

9. Clarence G. Golueke, SERL Report No. 70-2, Sanitary Engineering Research Laboratory, University of California at Berkeley, January 1970.

10. Deh B. Chan and E. A. Pearson, SERL Report No. 70-3, Sanitary Engineering Research Laboratory, University of California at Berkeley, October 1970.

11. F. F. Wangaard, Forest Products Journal, p. 53, February 1966.

12. G. E. Symons and A. M. Buswell, Journal of the American Chemical Society, p. 2028, 1933.

13. Edward G. Locke, Forest Products Laboratory, Report No. 2179, August 1960.

14. J. A. Hall, J. F. Saeman, J. F. Harris, Unasylva, p. 7, February 1956.

15. Merrill A. Millet, Andrew J. Baker, and Larry D. Satter, "Pretreatments to Enhance Chemical, Enzymatic and Microbiological Attack of Cellulose Materials," Forest Products Laboratory, June 1974.

Preceding page blank

16. F. Bender, D. P. Heaney, and A. Bowden, Forest Products Journal, p. 36, April 1970.

17. Private communication between Malcolm D. Fraser, InterTechnology Corporation, and J. F. Matthews, University of Saskatchewan, September 9, 1974.

18. Private communication between Malcolm D. Fraser, InterTechnology Corporation, and Merrill A. Millet, Forest Products Laboratory-Madison, September 4, 1974.

19. M. A. Millet, A. J. Baker, W. C. Feist, R. W. Mellenberger, and L. D. Satter, Journal of Animal Science, p. 781, October 1970.

20. Harold H. Brownell, Tappi, p. 298, July 1968.

21. John C. Pew and Philip Weyna, Tappi, p. 247, March 1962.

22. Private communication between Malcolm D. Fraser, InterTechnology Corporation and Harold H. Brownell, Forest Products Laboratory-Ottawa, September 9, 1974.

23. Motoyoshi Oshima, Wood Chemistry-Process Engineering Aspects, Noyes Development Corporation, 1965.

24. J. F. Harris, J. F. Saeman, and E. G. Locke, Forest Products Journal, p. 248, September 1958.

25. Private communication between Malcolm D. Fraser, InterTechnology corporation, and Michael T. Charters, Bauer Brothers Company, September 5, 1974.

26. Private communication between Malcolm D. Fraser, InterTechnology Corporation, and M. E. Ginaven, Bauer Brothers Company, December 3, 1974.

27. J. D. MacLean, American Wood-Preservers' Association Proceedings, p. 155 1951.

28. Wilbur N. Torpey, Sewage and Industrial Wastes, p. 121, February 1955.

29. Anaerobic Biological Treatment Processes, Advances in Chemistry Series 105, American Chemical Society, p. 91, 1971.

30. An example of a suitable feeder is the Bauer Brothers Feeder Presteamer.

31. An example of a suitable rotary valve is the Bauer Brothers 12 x 14 x 24 Inlet Rotary Valve.

32. An example of a suitable digester is the Bauer Brothers M&D Digester, which is used for various pulping processes.

33. An example of a suitable disk attrition mill is the Bauer Brothers No. 420 with disk diameter of forty inches. This particular mill accepts pressures up to only 165 psia, but it should not be very difficult to develop a mill from this technology which can handle a somewhat higher pressure (180 psia, for example).

34. An example of a suitable steam digester is the horizontal tube steam digester manufactured by Bauer Brothers for processing various wood materials.

35. One example of a manufacturer who could fabricate this pressure vessel is the Nooter Corporation.

36. The mixer can be provided by, for example, the Mixing Equipment Company (Lightnin Mixers).

37. M. S. Peters and K. D. Timmerhaus, "Plant Design and Economics for Chemical Engineers," McGraw-Hill, New York, 1968.

38. Private communication between Malcolm D. Fraser, InterTechnology Corporation and John E. Foley, Envirotech Corporation, December 10, 1974.

39. Black and Veatch, "Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities," PB-211 132, October 1971.

40. R. N. Maddox, "Gas and Liquid Sweetening, John M. Campbell, Norman, Oklahoma, 1974.

41. Private communication between Malcolm D. Fraser, InterTechnology Corporation and Wm. Van Scoy, Shell Development Company, March 3, 1975.

42. Private communication between Malcolm D. Fraser, InterTechnology Corporation, and J. R. Clark, Benfield Corporation, March 12, 1975.

43. K. M. Guthrie, Chemical Engineering, p. 114, March 24, 1969.

44. Private communication between Malcolm D. Fraser, InterTechnology Corporation, and Robert Caldwell, CE-Natco, March 17, 1975.

45. "Technology for the Conversion of Solar Energy to Fuel Gas", Report No. NSF/RANN/SE/GI 34991/PR/73/4, October 31, 1973.

46. W. H. Boshoff, Tropical Science, p. 155, May 1963.

47. W. S. Wilkinson, Curtis Barber, and F. E. Knox, Journal Agricultural and Food Chemistry, p. 665, July-August 1968.

48. G. L. Christopher, "Technology for Conversion of Solar Energy to Fuel", Report No. N911599-5, NSF Grant No. GI-34991, January 1974.

APPENDIX E

PROCESS ENGINEERING OF SOLID-FUELS PRODUCTION AND FIRING

TABLE OF CONTENTS

I. INTRODUCTION

The use of solid fuel produced from Energy Plantations on Army bases in unurbanized localities is discussed in some detail in sections III and IV in Appendix B. It is noted there, for instance, that solid fuel cannot be used very effectively in the small-capacity unattended heaters which are currently in widespread use at troop training centers. To use solid fuel at these Army bases would require installation of large-capacity central heating plants capable of firing solid fuel and a heat-distribution system to distribute steam or hot water to the numerous buildings now serviced by small space and water heaters. Whether the installation of such a central system is to be preferred over other ways of using Energy Plantation fuel, such as by converting it to synthetic natural gas, depends on the relative costs of the systems.

In this appendix, the costs for installing central heating and a heat-distribution system which would use solid fuel are calculated in an approximate manner by considering only the major equipment and facilities required. More precise costs can be estimated only by considering the exact layout of buildings and heaters for a particular Army base. Approximate costs can still be useful in determining the desirability of such a system because if they are significantly higher than an alternative approach for using Energy Plantation fuel, a solid-fuel-based system can be eliminated from consideration without making a detailed design.

Specifically included in the capital-cost estimates are the boilers which are assumed to generate saturated steam at 165 psia, precipitators on the boilers for controlling particulate emissions through their stacks, and a steam-distribution system based on an idealized layout of buildings. A rough estimate is included for alterations to buildings, and additional equipment such as fuel-handling and storage facilities, a fuel-drying system, site preparation, circulation pumps, and buildings are included in an additional lump sum.

The capital and operating costs of a solid-fuel-based system, and trade-offs between them, depend on certain aspects of the system design. For instance, all of the boilers can be located in a central heating plant, or they can be dispersed. In the former case, the fuel-handling costs and labor costs are minimized, for instance, and in the latter, the cost of the distribution system may be somewhat lower. It is assumed here that all of the boilers are in one central location, but several boilers will be assumed to ensure the reliability of the system.

Another important design feature is how the condensate is handled. If the condensate is not returned to the boiler, the capital expense of a condensate-return system is avoided, but additional operating costs are incurred for treating the boiler feedwater and for heating it to its boiling point. Additional fuel is required, and in the case of an Energy Plantation, greater land area is then required to provide the additional fuel. Systems with and without condensate return are considered to illustrate the differences in at least the major costs.

In the following two sections, solid-fuel-based systems are described for Forts Leonard Wood and Benning. Capital and operating costs are estimated and compared with those for a system based on conversion of Energy Plantation fuel to synthetic natural gas.

II. SYSTEM FOR FORT LEONARD WOOD

II.A. Boiler Capacity and Cost. The necessary boiler capacity for a central heating plant at Fort Leonard Wood depends on the energy usage at the base and the seasonal pattern in that usage. The normally expected maximum monthly heat load at Fort Leonard Wood, as shown on Table A-XIV, Appendix A, is estimated to be 340×10^9 Btu per month, which on an hourly basis is an average load of 0.47×10^9 Btu per hour. The lowest normally expected monthly load is estimated to be 80×10^9 Btu per month, or on an hourly basis, an average of 0.11×10^9 Btu per hour.

These hourly loads are averages over the whole month. Actually, instantaneous loads will be considerably higher, particularly in the case of the minimum load, which occurs mostly during the daytime. Thus, the boiler capacity required to handle the minimum load should be perhaps twice the average load plus another fifty percent of this instantaneous capacity for reserve, or about 0.33×10^9 Btu per hour.

The difference between the maximum load and the minimum load is the needed capacity for space heating, and this capacity is 0.36×10^9 Btu per hour plus fifty percent for reserve, or about 0.54×10^9 Btu per hour.

The total boiler capacity required, therefore, is about 0.87×10^9 Btu per hour of which about one-third is for meeting the base load in summertime and should be handled by one boiler. Thus, to meet the required load at Fort Leonard Wood, three boilers are indicated, each with a firing capacity of 0.30×10^9 Btu per hour.

If the same efficiency of heat delivery--65 percent--is assumed for the direct-fired space heaters now in use and for steam boilers fired with solid fuel from an Energy Plantation, boilers having a firing capacity of 0.30 x 10^9 Btu per hour will be capable of delivering 0.20 x 10^9 Btu per hour in steam. If the steam is generated at 165 pounds per square inch absolute from condensate at 212°F, each pound of steam on being condensed will deliver about 1000 Btu. Therefore, each boiler should have a capacity to deliver 0.20 x 10^9 pounds of steam per hour.

The estimated cost of one of these boilers has been derived by adjusting information from a recent reference[1]. The cost of a field-erected, gas or oil-fired unit obtained from the reference was multiplied by a cost index to bring the data up to date and by a factor of one-and-a-half to develop the cost for a solid-fuel-fired unit. The cost of a solid-fuel-fired unit is at least fifty percent more than a gas or oil-fired unit[2] and possibly even more than that[3]. The cost for the three boilers needed at Fort Leonard Wood as developed on this basis is about $11,840,000.

<u>II.B. Precipitator Cost</u>. The necessary precipitator capacity has been calculated from the volume of flue gas which would be generated from the boilers operating at capacity. This volume has been estimated assuming that the plant material as fired contains thirty percent moisture, that its oven-dry composition is seventy-seven percent carbohydrates and twenty-three percent lignin and that twenty percent excess air is used for its combustion. The flue-gas temperature entering the precipitator is assumed to be 500° Fahrenheit.

With these assumptions, the volume of flue gas generated by each boiler operating at capacity should be about 132,000 cubic feet per minute. An installed cost for a precipitator with this capacity for each boiler was obtained from a recent reference[4]. Again a cost index was applied to bring the cost estimate up to date as of December 1974. The cost for the three precipitators for the three boilers in the central heating plant at Fort Leonard Wood is estimated to be about $930,000.

II.C. Steam-Distribution System and Cost. The design, and hence the cost, of a heat-distribution system are intensely dependent on the layout of the buildings and heaters and other energy users at the Army base. To get a precise cost estimate requires a detailed design. However, an idealized model of a distribution system which would be suitable and adequate for the needs of a particular Army base can be set up, and approximate costs calculated on this basis. Such an approximate cost estimate would at least be useful for comparing alternative systems.

From a map of Fort Leonard Wood, it can be seen that the main area containing buildings is very roughly a rectangle about one and one-half miles by two and one-quarter miles. There are 1474 small heaters on the base (see Table A-V). If it can be assumed that each building contains two heaters, there are about 737 buildings on the base in which small heaters are used. If these buildings are scattered uniformly throughout this rectangular area in square plots about the same size, the rectangle would be divided into thirty-three units along its length and twenty-two units along its width. Suppose that There are eleven streets running along the length of the rectangle. Assume further that the central heating plant is located at the center of the rectangle with two main steam headers, each extending for 0.75 miles in a direction along the width of the rectangle and each carrying one-half of the steam. To service the buildings would then require eleven distribution lines from the main headers on each side, running along the streets. There would be twenty-two distribution lines in all, each one and one-eighth mile in length and carrying one twenty-second of the steam. Assume that each building is about fifty feet from the street requiring a tap line from the distribution line of about this length. Similar lengths of condensate-return pipe would be required if condensate is to return to the central plant.

The size of the pipe required can be determined approximately by sizing each pipe to carry its capacity load at an economic velocity, which for steam is about a maximum of 200 feet per second and condensate about ten feet per

second. On this basis, the main steam headers should be eight-inch-diameter pipe, the distribution lines three-inch pipe, and the tap lines about one inch or less. The corresponding sizes for condensate-return pipe would be three inch, one inch, and perhaps one-half inch.

For practical reasons as well as esthetics, the steam-distribution system should be buried in the ground rather than supported overhead. Costs for buried pipelines for district heating systems were obtained from a recent reference[5]. The costs given are for two-pipe systems in which the pipes are insulated and buried in concrete with appropriate hangers and expansion joints and other necessary hardware. To arrive at the cost for a one-pipe system--in other words, with no condensate-return pipe--the installed cost for insulated pipe was subtracted from the system price, there being no savings in trenching cost.

The system costs were brought up to date by multiplying by a factor of two, which appears to be an appropriate cost index factor for this type of sy[illegible]tem[6]. The piping-only costs were obtained from other references[1,7]. The c[illegible]or a system with a smaller condensate-return pipe were obtained by addi[illegible]e pipe-only cost for the appropriate size to the cost of the bu[illegible] one-pipe system.

The cost of the steam-distribution system with these assumptions is shown in Table E-I for systems with and without a condensate-return system. Without condensate return, a system costs \$10.6 million, and with condensate return, \$11.4 million.

<u>II.D. Total Capital and Operating Costs</u>. The total estimated capital costs are summarized in Table E-II. A cost of \$5,000 has been assumed as the cost of alterations to a building to accommodate a central heating system. The [illegible]tal cost for this item is taken as \$5,000 times 737, the estimated number of buildings. A lump sum has also been included in the total capital costs for items not estimated separately, such as site preparation, buildings, fuel-handling and fuel-

TABLE E-I

ESTIMATED COST OF STEAM-DISTRIBUTION SYSTEM FOR FORT LEONARD WOOD

	Pipe	Size	Installed Cost, $/ft	Length ft	Cost $
1.	Without Condensate Return:				
	Steam Header	8"	87.60	7,920	694,000
	Steam-Distribution Lines	3"	63.60	130,680	8,311,000
	Steam Tap Lines	1"	44.60	36,850	1,644,000
					$10,649,000
2.	With Condensate Return:				
	Steam Header + Condensate Return	8" 3"	99.70	7,920	790,000
	Steam Distribution + Condensate Return	3" 1"	68.20	130,680	8,912,000
	Steam Tap Lines + Condensate Return	1" 1/2"	46.90	36,850	1,728,000
					$11,430,000

drying equipment, utilities connections, steam and condensate pumps and design. The estimated total capital cost is about $35 million with condensate return and $34 million without. These capital cost estimates do not include the cost of the plantation required for producing the solid fuel to be used in the system.

The operating costs are also listed in Table E-II. The largest cost is for the solid fuel from the Energy Plantation. With condensate return, about 180,000 tons are required for the necessary energy input of about 2.08×10^{12} Btu per year required by Fort Leonard Wood. Without condensate return, more fuel is needed because heat is lost with the condensate and the water must be heated from a lower temperature--for example, 60° Fahrenheit. About 42,000 more tons of fuel would have to be provided.

Electricity is required to run pumps as well as for other purposes. An average power expenditure of 1000 horsepower has been assumed.

The cost for treatment of once-through boiler feedwater--filtration and softening--was taken from a recent reference[8] with a factor of two--the change in wholesale commodity prices between 1967 and 1975--applied to account for changes with time. This cost is $0.80 per thousand gallons. With a condensate-return system, a certain amount of makeup water will be needed, and this makeup is assumed to be twenty-five percent. In addition, the returning condensate will have to be treated to get rid of grease and oil picked up in the lines. This condensate-treatment cost is assumed to be an amount similar to the treatment cost for the makeup water.

For operating labor, two boiler crews of two men each plus one fuel-handler have been assumed for around-the-clock operation (four shifts) at an average wage of $5 per hour.

TABLE E-II

ESTIMATED TOTAL CAPITAL AND OPERATING COSTS FOR SOLID-FUEL-BASED CENTRAL HEATING SYSTEM AT FORT LEONARD WOOD

Capital Cost*	Without Condensate Return	With Condensate Return
Boiler Cost	$11,840,000	$11,840,000
Precipitator Cost	930,000	930,000
Steam-Distribution Cost	10,650,000	11,430,000
Building Alterations	3,685,000	3,685,000
	27,105,000	27,885,000
+25% for Unestimated Items	6,776,000	6,971,000
Total Estimated Capital Cost	$33,881,000	$34,856,000
Operating Cost		
Fuel (@ $12.65 per ton)	2,808,000	2,277,000
Electricity (6.53×10^6 kWh x $0.0098/kWh)	64,000	64,000
Treatment of Boiler Feedwater	200,000	100,000
Operating Labor (20 x $5/hr x 2080 hr)	208,000	208,000
Maintenance Labor (60 x $5/hr x 2080 hr)	624,000	624,000
Supervision & Clerical	144,000	144,000
Administrative & General Overhead	390,000	390.000
Operating Supplies	62,000	62,000
Maintenance Supplies	600,000	600,000
Total Estimated Annual Operating Cost	$ 5,100,000	$ 4,469,000
Estimated Annual Replacement Cost	1,745,000	1,787,000
Total Estimated Annual Cost	$ 6,845,000	$ 6,256,000

---

*The estimated capital cost does not include the capital cost of the plantation.

For maintenance labor, about two percent of total capital cost has been assumed, which work out to about 60 people. Again, an average pay rate of $5 per hour has been assumed. A large proportion of these maintenance people will be needed to maintain the steam-distribution system.

A total of eight people in the supervision and clerical category has been assumed. These eight people consist of one superintendent, one operating foreman, one maintenance foreman, four shift foremen, and one clerk-typist for a total salary cost of about $144,000.

Administrative and general overhead is taken as 0.4 times the sum of operating labor, maintenance labor, and supervision and clerical expenses. Operating supplies is taken as 0.3 times operating labor. Maintenance supplies are taken as two percent of total capital costs.

Replacement costs must also be considered. A startup cost of 0.2 times the annual operating cost is assumed also as a replacement cost. The replacement of the total capital cost and this startup cost is assumed to take place over a period of twenty years.

The total annual cost, including both operating costs and replacement costs, of operating a solid-fuel-based central heating system at Fort Leonard Wood is estimated to be about $6.8 million without condensate return and $6.3 with condensate return. It should be noted that these costs would be 30 to 50 percent higher if the heating system were to be operated by a contractor, who would have higher overhead and who would also have to include other costs in the total such as return on capital.

These costs for a solid-fuel-based central heating system at Fort Leonard Wood can be compared to the costs for an SNG-based heating system. The total capital cost for an SNG-based system is $25.3 million, before allowance for the capital cost of the plantation. The total annual cost is about $8 million, including replacement costs.

III. SYSTEM FOR FORT BENNING

III.A. Boiler Capacity and Cost. The calculations involved in determing adequate boiler capacity for a solid-fuel-based system at Fort Benning are exactly the same as illustrated in the preceding section on Fort Leonard Wood. The maximum monthly average heat load at Fort Benning, as shown on Table A-XIV, Appendix A, is 353 x 10^9 Btu per month or 0.49 x 10^9 Btu per hour. The minimum monthly average is 132 x 10^9 Btu per month or 0.18 x 10^9 Btu per hour.

Thus, the boiler capacity required to handle the minimum load should be about 0.54 x 10^9 Btu per hour. The needed capacity for space heating should be about 0.47 x 10^9 Btu per hour, which is the difference between maximum and minimum loads plus about 50 percent for reserve capacity.

The total boiler firing capacity required, therefore, is about 1.01 x 10^9 Btu per hour, of which about one-half is the base load. Four boilers can handle this load, each with a firing capacity of 0.25 x 10^9 Btu per hour. With an assumed efficiency of 65 percent and the same steam-generating conditions--saturated steam at 165 psia--each boiler will deliver about 0.16 x 10^6 pounds of steam per hour.

The cost for one of these boilers has been developed in the same manner as the boiler costs for Fort Leonard Wood. On this basis, each boiler at Fort Benning will cost about $3,345,000. The cost for all four boilers is about $13,380,000.

III.B. Precipitator Cost. The volume of flue gas generated by each boiler operating at capacity should be about 111,000 cubic feet per minute. A precipitator with sufficient capacity to clean the flue gas from two boilers should cost about $445,000. The total estimated cost for precipitators in a central heating plant at Fort Benning is then $890,000.

III.C. Steam-Distribution System and Cost. From a map of Fort Benning, it can be seen that the main area containing buildings is very roughly a rectangle about one and two-thirds miles by two and one-third miles. No data are available on the number of buildings with small heaters at Fort Benning, but an approximate estimate can be obtained from a comparison involving the number at Fort Leonard Wood, the difference in the severity of winter between Forts Leonard Wood and Benning and the fuel consumption in small heaters at the two posts.

Reference to Tables A-V and A-VIII shows that there are 1,474 small heaters at Fort Leonard Wood which, in fiscal 1973, consumed fuels having a total heating value of 1,221 billion Btu, or an average of about 0.83 billion Btu per heater. Using equation A-2 to estimate the fuels consumption index at Forts Leonard Wood and Benning, the indices are estimated to be 1.24 and 0.90, respectively, for the bases. Therefore, it would be expected that small heaters at Fort Benning would consume on average about (0.90/124) x 0.83 billion Btu per year, or about 0.6 billion Btu per heater per year. Total fuel consumption in small heaters at Fort Benning in fiscal 1973 was 1,204 billion Btu (see Table A-VII) which suggests that there are about 2,000 small heaters at the post. Assuming that any building with small heaters has two of them (one for hot water and another for space heating), there are about one thousand buildings at Benning equipped with small heaters.

If the buildings having small heaters at Fort Benning are scattered approximately uniformly throughout the roughly rectangular built-up area in square plots about the same size, the rectangle will be divided into about thirty-six units along its length and twenty-eight along its width. Suppose that there are fourteen streets running along the length of the rectangle.

Assume further that the central heating plant is located at the center of the rectangle with two main steam headers, each extending for about five-sixths of a mile in a direction along the width of the rectangle and each carrying one-half of the steam. To service the buildings would then require fourteen distribution lines from the main headers on each side, running along the streets. There would be twenty-eight distribution lines in all, each carrying one-twenty-eighth of the steam. Assume that each building is about fifty feet from the street, requiring a tap line from the distribution line of about this length. Similar lengths of condensate-return pipe would be required if condensate is to be returned to the central plant.

The same pipe diameters for the various lines will be assumed for Fort Benning as for Fort Leonard Wood as the maximum boiler capacities are not greatly different.

The costs for the steam-distribution system were calculated using the same basic information used for Fort Leonard Wood. The costs are shown in Table E-III. Without condensate return, a system costs about \$14 million, and with condensate return, \$15 million.

III.D. Total Capital and Operating Costs. The total capital costs are summarized in Table E-IV. The total capital cost is about $43 million with a condensate-return system and $42 million without one. These capital cost estimates do not include the capital cost of the plantation required for the solid fuel to be used in the system.

The operating costs are also listed in Table E-IV. With condensate return, about 216,000 tons of Energy Plantation fuel are required for the necessary energy input of about 2.51×10^{12} Btu per year required by Fort Benning. Without condensate return, about 51,000 more tons of fuel would have to be provided.

The operating costs for the system at Fort Benning are calculated with the same assumption and on the same bases as the costs calculated for Fort Leonard Wood. More maintenance is required because of the larger investment to maintain.

The total annual cost, including both operating costs and replacement costs, of operating a solid-fuel-based heating system at Fort Benning is about $8.1 million without condensate return and $7.4 million with condensate return.

For an SNG-based system at Fort Benning, the total capital cost is $31.2 million. The total annual cost is about $10.6 million.

TABLE E-III

ESTIMATED COST OF STEAM-DISTRIBUTION SYSTEM FOR FORT BENNING

	Pipe	Size	Installed Cost, $/ft	Length ft	Cost $
1.	Without Condensate Return:				
	Steam Header	8"	87.60	8,820	$ 772,000
	Steam-Distribution Lines	3"	63.60	172,230	10,954,000
	Steam Tap Lines	1"	44.60	50,000	2,230,000
					$13,956,000
2.	With Condensate Return:				
	Steam Header + Condensate Return	8" 3"	99.70	8,820	879,000
	Steam Distribution + Condensate Return	3" 1"	68.20	172,230	11,746,000
	Steam Tap Lines + Condensate Return	1" 1/2 "	46.90	50,000	2,345,000
					$14,970,000

TABLE E-IV

ESTIMATED TOTAL CAPITAL AND OPERATING COSTS FOR SOLID-FUEL-BASED CENTRAL HEATING SYSTEM AT FORT BENNING

Capital Cost*	Without Condensate Return	With Condensate Return
Boiler Cost	$13,380,000	$13,380,000
Precipitator Cost	890,000	890,000
Steam-Distribution Cost	13,952,000	14,970,000
Building Alterations	5,000,000	5,000,000
	$33,226,000	$34,240,000
+25% for Unestimated Items	8,306,000	8,560,000
Total Estimated Capital Cost	$41,532,000	$42,800,000
Operating Cost		
Fuel (@ $12.47 per ton)	$ 3,329,000	$ 2,694,000
Electricity (6.53×10^6 kWh x $0.0183 per kWh)	119,000	119,000
Treatment of Boiler Feedwater	241,000	120,000
Operating Labor (20 x $5/hr x 2080 hr)	208,000	208,000
Maintenance Labor (70 x $5/hr x 2080 hr)	728,000	728,000
Supervision & Clerical	144,000	144,000
Administrative & General Overhead	432,000	432,000
Operating Supplies	62,000	62,000
Maintenance Supplies	700,000	700,000
Total Estimated Annual Operating Costs	$ 5,963,000	$ 5,207,000
Estimated Annual Replacement Cost	2,136,000	2,192,000
Total Estimated Annual Cost	$ 8,099,000	$ 7,399,000

---

*The estimated capital cost does not include the capital cost of the plantation.

Preceding page blank

IV. REFERENCE LIST

1. Kenneth M. Guthrie, Chemical Engineering, p. 114-142, March 24, 1969.

2. Chemical Engineers' Handbook, 4th Edition, p. 26-24.

3. Private communication between Malcolm D. Fraser, InterTechnology Corporation, and Leo Cohan, Combustion Engineering, May 22, 1975.

4. A. Eugene Vandegrift, et al., Chemical Engineering, p. 111, June 18, 1973.

5. Oak Ridge National Laboratory, "Use of Steam-Electric Power Plants to Provide Thermal Energy to Urban Areas," Contract No. W-7405-eng-26, ORNL-HUD-14, January 1971.

6. Private communication between Malcolm D. Fraser, InterTechnology Corporation, and Anthony Iachetta, University of Virginia, June 2, 1975.

7. D. A. Bosworth, Chemical Engineering, p. 132, March 25, 1968.

8. Max. S. Peters and Klaus D. Timmerhaus, Plant Design and Economics for Chemical Engineers, Second Edition, 1968.

APPENDIX F

ENERGY PLANTATION FOR FORT LEONARD WOOD

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

I. INTRODUCTION AND SUMMARY

A general description of the geography, soil, climate, terrain and vegetation in the Fort Leonard Wood area is given in Appendix H.

No data are known to have been collected in the neighborhood of Fort Leonard Wood on yields of harvestable plant material for any species suitable for Energy Plantations. Data generated in other localities can be used, however, for estimating yields to be expected on and in the vicinity of the fort. Suitable yield data have been collected at two sites having climate and soils similar to those in the Fort Leonard Wood area for several hybrid poplars (in central Pennsylvania) and for Sioux and Missouri cottonwood (near Manhattan, Kansas). Data collected in other regions, where the climate is rather different from that at the fort, can also be used as bases for yield estimates by application of the estimation techniques described in Appendix C. Such data include yields from eastern cottonwood grown in west central Mississippi and from sycamore grown in northwestern Georgia. Yields as functions of planting density and harvest cycle have already been determined for these several species (see Appendix C, section VIII) at the sites for which data have been collected for them.

The first step in this appendix is to compare the growth potential of the Fort Leonard Wood area with the potentials in the areas where yield data are available for deciduous species of interest for plantations at the fort. The yields from these areas are then adjusted to allow for the effect of climate and other factors at Fort Leonard Wood. Only deciduous species are considered because it has been shown that warm-season perennial grasses are not satisfactory for plantations in central Missouri.

Based on these comparisons between the Fort Leonard Wood region and the others for which yield data are available, species are selected for consideration for plantations at the fort. A range of average annual sustained yields are estimated for these species at and in the immediate environs of the fort as functions of planting density and harvest cycle. It is found that the smallest plantation area required for meeting the fuel requirement at Fort Leonard Wood will be achieved with a planting density of about eleven thousand plants per acre, the first harvest taken when the stand is a year old and subsequent harvests taken at two-year intervals. Under these conditions, average annual sustained yields ranging from about seven to about nine tons (oven-dry basis) per acre-year are predicted.

Analysis of plantation field operations, clone production, maintenance of field equipment and plantation supervision leads to the conclusion that plantation units having a capacity for producing about 40,000 tons (oven-dry basis) per year will make best year-long use of machinery and manpower. This finding is valid for deciduous-species plantations in all localities suitable for Energy Plantations. Capital and operating costs for such a unit at Fort Leonard Wood have been estimated on the basis of the price level in effect in December 1974. If the fuel needs of the fixed facilities at Fort Leonard Wood are to be met with SNG produced from plant material grown in a plantation at or near the fort, six such plantation units will be required. If the fuel used is to be met with solid fuel grown in the plantation, four and a half plantation units will be needed.

The cost of plant material has been estimated at three levels of plantation productivity spanning the anticipated range of yields from deciduous-species plantations having the smallest area capable of meeting the fuel requirement at the fort. The estimated cost of plant material for SNG production is between eleven and twelve dollars per ton,

and for solid fuel it is between twelve and thirteen dollars, the tons being expressed on an oven-dry basis. These costs are the equivalent of about $1.30 per thousand standard cubic feet of SNG produced and $1.10 per million Btu if solid fuel is produced from the plantations. It should be noted that if the plantation is operated for the Army by a contractor, these costs would be 30 to 50 percent higher because of higher overhead rates and the inclusions of certain capital charges such as return which have not been included here.

The costs for establishing plantations at the fort have also been estimated and are about $7.5 million for raw material for SNG production and $5.4 million for solid fuel. The plantation areas required are about 29,000 and 22,000 acres for SNG raw material and solid fuel, respectively.

Sensitivity analysis reveals that if land availability is not a critical element and, more specifically, if about fifteen percent more than previously mentioned can be made available, the cost of plant material will be reduced by about one dollar per ton (oven-dry basis) for solid fuel and for SNG raw material. The costs of establishing the plantations will be reduced by about fifteen percent also. These lower costs will be achieved with a planting density of about 5,500 plants per acre and a harvest schedule in which the first harvest is taken when stands are a year old with subsequent harvests at three-year intervals.

II. COMPARISON BETWEEN THE FORT LEONARD WOOD AREA AND AREAS FOR WHICH YIELDS OF DECIDUOUS-TREE PLANTATIONS HAVE BEEN ESTIMATED

II.A. General Geographic and Climatic Characteristics. The main geographic and climatic characteristics of the localities considered in estimating plantation yields at Fort Leonard Wood are shown in Table F-I. Conditions at Fort Leonard Wood, Manhattan, Kansas, and State College, Pennsylvania, are fairly similar, while the Georgia and Mississippi sites display significantly milder winters and warmer summers. The latter two have substantially longer frost-free periods, more total precipitation, higher average annual temperatures and more days per year when the temperature is over ninety degrees Fahrenheit than do the three more northerly sites. This comparison suggests that the two southern sites have better growth potential than the other three. However, as has been shown in section IV.B.9. of Appendix C, a rather detailed analysis is necessary to compare the growth potential between sites.

II.B. Comparison of the Sites of Interest on the Basis of Temperature Distribution, Insolation and Rate of Photosynthesis. In section IV.B.9.b. of Appendix C, a method is developed for estimating the amount of plant matter produced in a growing season on the basis of the photosynthesis rate, temperature distribution and insolation. The procedure, which is described in detail in Table C-XVI, has been applied to the localities shown in Table F-I. The results are given in Table F-II. The "high" value of y_n/y_o (see page C-131 for definition of the symbols) is an estimate of the plant-matter increase over a growing season for young plants (two years old or younger) in which all leaves contribute to photosynthesis while the "low"

value corresponds to plants in their third year or older for which only about twenty percent of the leaf area contributes to photosynthesis. Comparison of the plant-matter production ratios y_n/y_0 for Fort Leonard Wood with those for the other locations indicates that the growth potential of Fort Leonard Wood is expected to be very similar to that of Athens, Georgia, very slightly greater than that for the Pennsylvania site, greater than that for the Kansas location and a little less than that for the Mississippi site.

It is concluded that the combined effect on growth rates of differences in photosynthesis rates and temperature profiles and insolation rates during the growing season will be about the same at each of the five localities shown in Table F-I.

II.C. Comparison of the Sites of Interest on the Basis of Soil Quality and Moisture Available During the Growing Season. Differences in soil quality between the sites, if large enough, could cause significant differences in growth potential between the sites. The largest area of land suitable and probably available for an Energy Plantation around Fort Leonard Wood is on the sloping hillsides where the soil is a deep loam with a rather high fraction (up to fifty percent in places) of cherty dolomitic material and a relatively low level of plant nutrients. This type of soil is expected to respond reasonably well to fertilization[3], which means that nutrient level is not likely to be a factor limiting the growth potential of plantations at Fort Leonard Wood.

Another important factor, the effect of which is not included in the growth potential estimates in the previous section, is moisture available to the plants during the growing season. This moisture is supplied mostly

TABLE F-I

GENERAL GEOGRAPHIC AND CLIMATIC C .RACTERISTICS OF FORT LEONARD WOOD AND OTHER LOCALITIES

Factors	Fort Leonard Wood	Manhattan, Kansas	State College, Pennsylvania	Athens, Georgia	Stoneville, Mississippi
Latitude	N 37° 57'	N 39° 12'	N 40° 48'	N 33° 55'	N 33° 25'
Elevation - feet	1,202	1,065	1,175	685	127
Annual Normal Temp. - °F	55.5	55.1	49.7	62.0	63.7
Annual Normal Precipitation - in.	40.43	33.52	36.77	49.35	50.37
Annual Normal Heating Degree-Days	4,804	5,085	6,132	2,821	2,630
Annual Normal Cooling Degree-Days	1,362	1,501	583	1,748	2,189
Frost-Free Period - Days	178	183	158	244	252
Mean Number of Days with Temperature Over 90°F	43	53	24	57	68

Sources: References 1 and 2.

by water retained in the soil. The amount retained depends on the permeability and water-holding characteristics of the soil and on the frequency of soaking rains just before and during the growing season.

Normal monthly precipitation at each of the locations listed in Table F-I is shown in Figure F-I. Several notable differences in the precipitation profiles are apparent:

- the two southern locations have higher monthly rainfalls from November to April than do the more northerly ones;
- in May and June, high rainfall is recorded at Rolla in Missouri and in June at Manhattan, Kansas;
- from June to the end of October, the average monthly rainfall decreases at all locations; and
- monthly rainfall during the growing season, even at its lowest level (September and October) appears to be sufficient for sustaining high-yielding plantations (see Appendix C, section IV. B.9.d.).

Thus, on the basis of average monthly rainfalls, little differences should be observed between the growth potentials of the various sites.

However, the distribution of rainfall over time is important, particularly when the soil moisture retention capacity is relatively low, as is the case in the Missouri location. Heavy infrequent rainfalls which exceed the water assimilation rate of the soil are less effective for maintaining the soil-moisture content than is a succession of lighter rainfalls whose total precipitation is the same as that of the heavy ones. The distribution by months of the average number of days when precipitation is one-hundredth of an inch or more at the five locations of interest is shown in Figure F-II. It is

TABLE F-II

GROWTH POTENTIAL ESTIMATES FROM CLIMATIC DATA FOR LOCALITIES SHOWN IN TABLE F-I

	y_n/y_o low[1]	y_n/y_o high[2]	(y_n/y_o)L.W./(y_n/y_o) other[3] low[1]	(y_n/y_o)L.W./(y_n/y_o) other[3] high[2]
Fort Leonard Wood	1.87	14.37	-	-
Manhattan, Kansas	1.78	10.60	1.05	1.36
State College, Penn.	1.85	12.75	1.01	1.13
Athens, Georgia	1.87	14.57	1.00	0.99
Stoneville, Miss.	1.91	16.36	0.98	0.88

Notes:

1. For plants whose plant material above ground is three years old or older.
2. For plants whose plant material above ground is two years old or younger.
3. Ratios of y_n/y_o for Fort Leonard Wood to those of other locations.

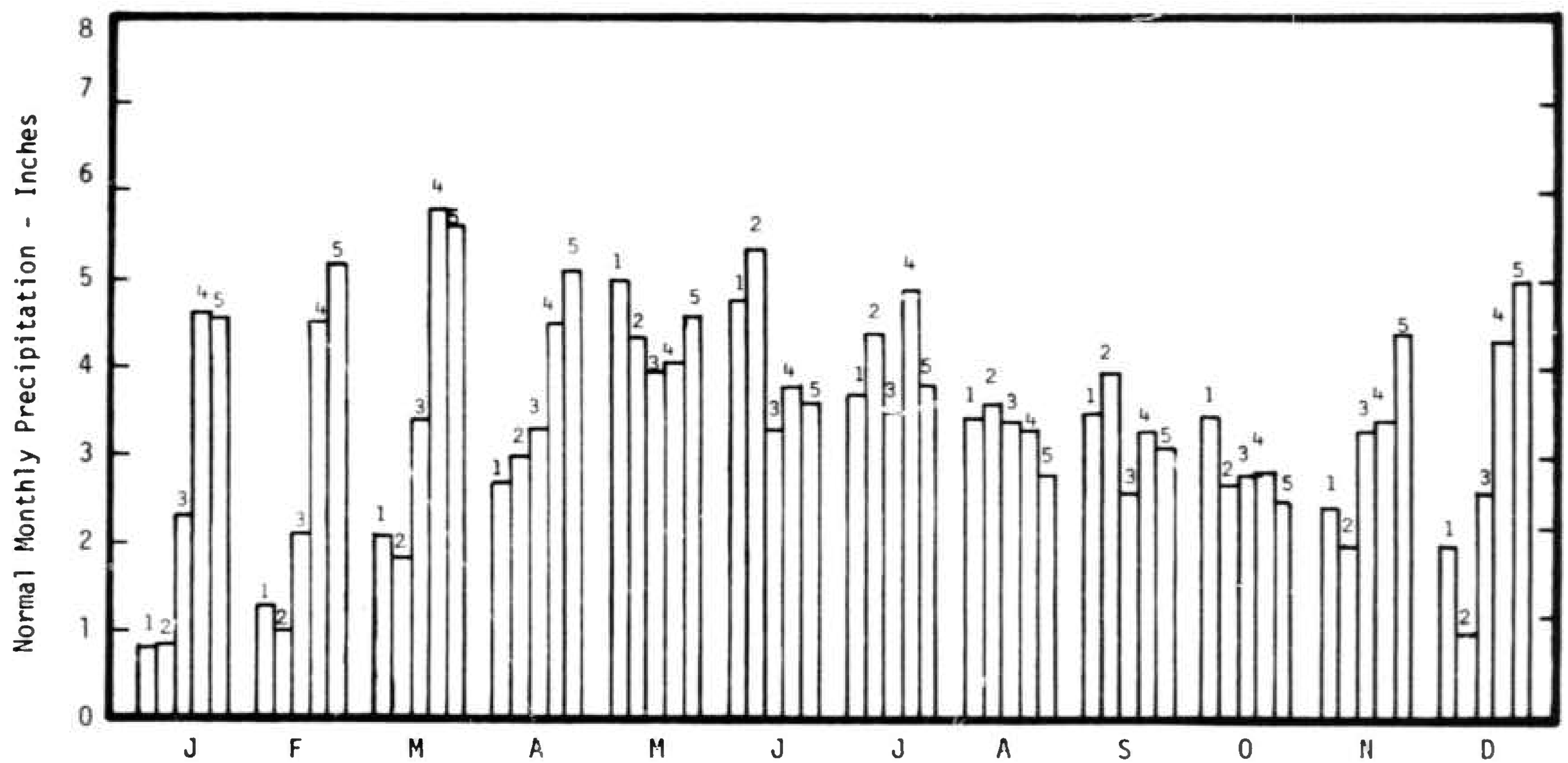
evident that for a given total precipitation per month, the larger the number of days with precipitation over 0.01 inches, the better the soil-moisture supply is likely to be.

<u>II.D. Growth Potential for Deciduous Species in the Fort Leonard Wood Area</u>. Climate data for Fort Leonard Wood and information collected locally during visits there suggest that deciduous species are to be preferred for an Energy Plantation for the post. The droughty period of about a month's duration normally expected in July and August reduces sharply the expected yields from perennial grasses. In fact, a hay yield of the order of only three to four air-dry tons per acre-year is generally recorded for the area, a yield which is too low for practical Energy Plantation operation. Deciduous species are also affected by droughty conditions, but the choice of drought-resistant varieties and the fact that their root systems generally reach deeper into the ground than do those of most grasses, favor deciduous species over grasses for plantation culture. The soil survey for Dent County[3] indicates that the soils of the Clarksville Series, which are the main candidates for Energy Plantations at Fort Leonard Wood, are in the woodland suitability group 1, that is they are best suited for wood crops and are unsuitable for agricultural crops, including grasses.

It has already been noted that before allowance is made for precipitation and its profile, the growth potentials of the five localities being considered are about equal. However, the rainfall frequency patterns shown in Figure F-II suggest that the growth potential is likely to be higher at Athens, Georgia, and State College, Pennsylvania, than at Fort Leonard Wood. At Athens, the number of days by months with precipitation equal to 0.01 inches or more is frequently the highest and always near the highest among the sites considered. The Kansas site is generally unfavorable as far as rain distribution is concerned. For all the sites, the number of

FIGURE F-I

NORMAL MONTHLY PRECIPITATION IN THE VICINITY OF THE LOCALITIES SHOWN IN TABLE F-I



1. Rolla, Missouri
2. Manhattan, Kansas
3. State College, Pennsylvania
4. Athens, Georgia
5. Stoneville, Mississippi

Source: Reference 4.

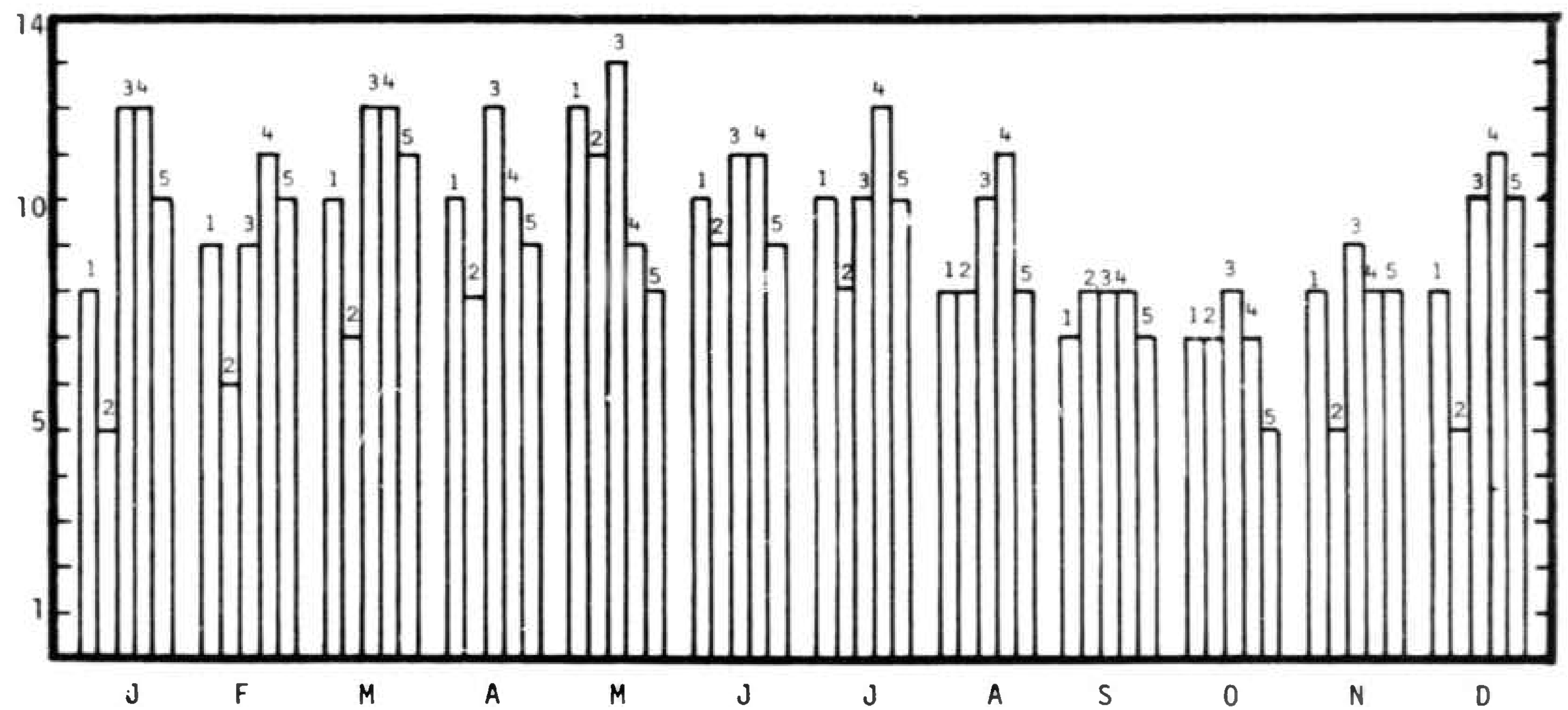
days with measurable precipitation per month in the period from June to October is relatively low. The facts that the frequencies are relatively constant during these months, as are the total precipitations (see Figure F-I), suggest that a limited number of downpours occurs during this period. As a consequence, a substantial part of the rain received during the latter part of the summer and early fall may be lost to run-off if the soil does not assimilate water readily.

This problem may be particularly acute in the case of the cherty Clarksville loams which are the main candidate for Energy Plantations at Fort Leonard Wood. The water-retention capacity of this soil is about two inches per foot of soil[3]. However, its mechanical analysis[3] shows that thirty-five percent of the material in the soil is smaller than 0.05 mm, about forty percent is smaller than 0.074 mm and about fifty-five percent is smaller than 0.42 mm. It is expected that diffusion of water through this fine-grained soil will be slow and probably inhibit absorption of water from heavy downpours of short duration.

Daily precipitation in the months of July, August and September at Rolla, Missouri is shown in Figure F-III by years for 1970 through 1973. As expected from the data in Figure F-II, the precipitation pattern displays relatively few days with rather heavy rainfall in these three-month periods, a situation which is unfavorable for maintaining a high moisture content in soils which are unlikely to absorb water very rapidly. Consider, for instance, the month of July in 1973. On the 23rd and 24th a total of about 3.6 inches of rain was recorded. Assuming that a full two inches of this rainfall could be absorbed in the top twelve inches of the soil, which is doubtful in view of the fine-grained character of the soil, more than one and one-half inches would be lost to run-off. The next major rain occurred nineteen days later, in mid-August. In this case, the precipitation pattern is more favorable, that is a total of about two inches fell over a four-day period. Similar patterns of heavy rains followed by dry spells are also

FIGURE F-II

AVERAGE NUMBER OF DAYS WITH PRECIPITATION EQUAL TO 0.01 INCHES OR MORE FOR THE LOCALITIES SHOWN IN TABLE F-I



1. Rolla, Missouri
2. Manhattan, Kansas
3. State College, Pennsylvania
4. Athens, Georgia
5. Stoneville, Mississippi

Source: Reference 1

recorded in 1971 and 1970. The only year in the series shown in Figure F-III which displays a more regular rainfall pattern in the three-month period is 1972. However, from the data available, this year appears to be exceptional.

The amount of soil moisture available to plants is also reduced through evaporation. Monthly data comparing rainfall and evaporation from water surfaces at Rolla and Lakeview, Missouri, respectively, are shown in Table F-III for the months of July, August and September for the period 1970 through 1973. The rates of evaporation, expressed in inches, are generally larger than the rainfall in July and August, but the opposite tends to be the case in September. The rates of evaporation shown in Table F-III are probably significantly higher than those for water from soil with a cover layer of plant litter and a canopy of the kind an Energy Plantation will provide. Nevertheless, evaporation will contribute to reduction of the moisture available in the soil for plant growth. This circumstance probably will be most critical immediately after planting and after harvesting because, at these times, there will be no plant canopy to help protect the soil surface from the sun. A droughty soil condition is therefore more likely to be experienced at these times than at others when the plants in the plantation provide a canopy over the ground. In the absence of a canopy, the rate of clone germination and even of stump survival may be affected adversely. To reduce the risk of plant mortality immediately after planting and harvesting, it is planned to complete planting before mid-May at Fort Leonard Wood and to seed the ground between clones and plants with a cover crop such as a clover which grows only five or six inches tall.

To summarize this analysis, the precipitation pattern and the nature of the soil at Fort Leonard Wood and its environs may create droughty conditions between about mid-July and mid-September. This condition will tend to limit yields from deciduous species more than would be expected from the insolation and temperature distribution during the growing season.

A comparison of the site indices for oak in natural stands at the Pennsylvania and the Missouri sites reflects the expected difference in potential productivity between these two localities. The site index for oak at State College, Pennsylvania, is about eighty[6], whereas the site index for oak around Fort Leonard Wood is between fifty-five and seventy-five. The site index for particular tracts in the vicinity of Fort Leonard Wood depends on orientation--for instance, north and east-facing sites have indices of about seventy, whereas south and west-facing sites have indices of about sixty[3].

Site indices are general indicators of the natural potential productivity of a site for a particular species. In view of the climate similarity, except for rainfall distribution, during the growing season at Fort Leonard Wood and at State College, Pennsylvania, the difference between the site indices for oak in natural stands between these localities is very likely to be substantially attributable to differences in their soil moisutre availabilities in summertime. Differences in the plant nutrient content of the soils in the two regions may also be partly responsible for the site index differences. However, differences attributable to soil nutrient content can be eliminated by the fertilization and soil productivity maintenance and enhancement contemplated in Energy Plantation management. Thus, the productivity for deciduous species at Fort Leonard Wood cannot be expected to be less than between about eighty-five and ninety percent of the productivity at State College, Pennsylvania.

FIGURE F-III

PATTERNS OF PRECIPITATION AT ROLLA, MISSOURI, FOR THE MONTHS OF JULY, AUGUST AND SEPTEMBER IN THE YEARS FROM 1970 TO 1973

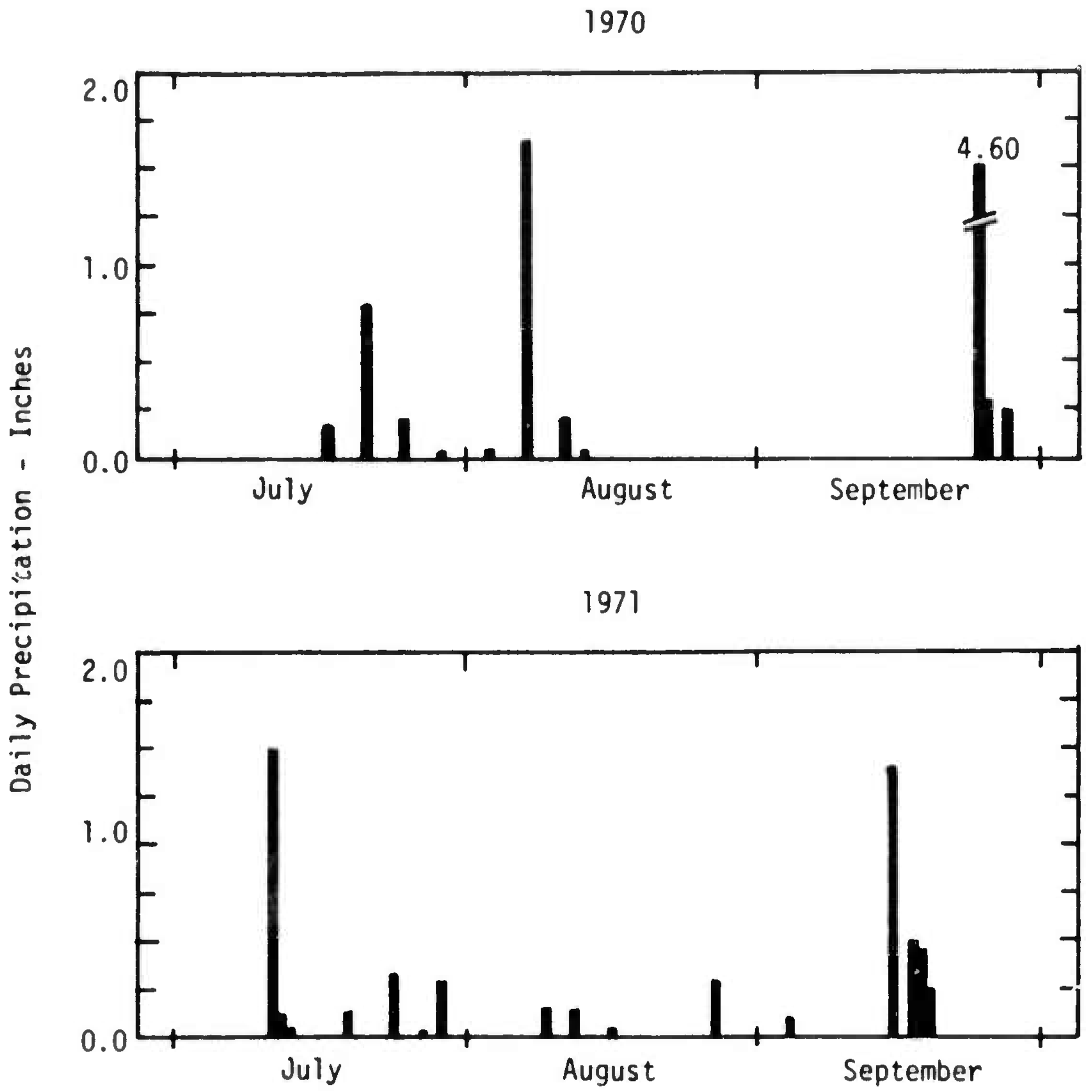
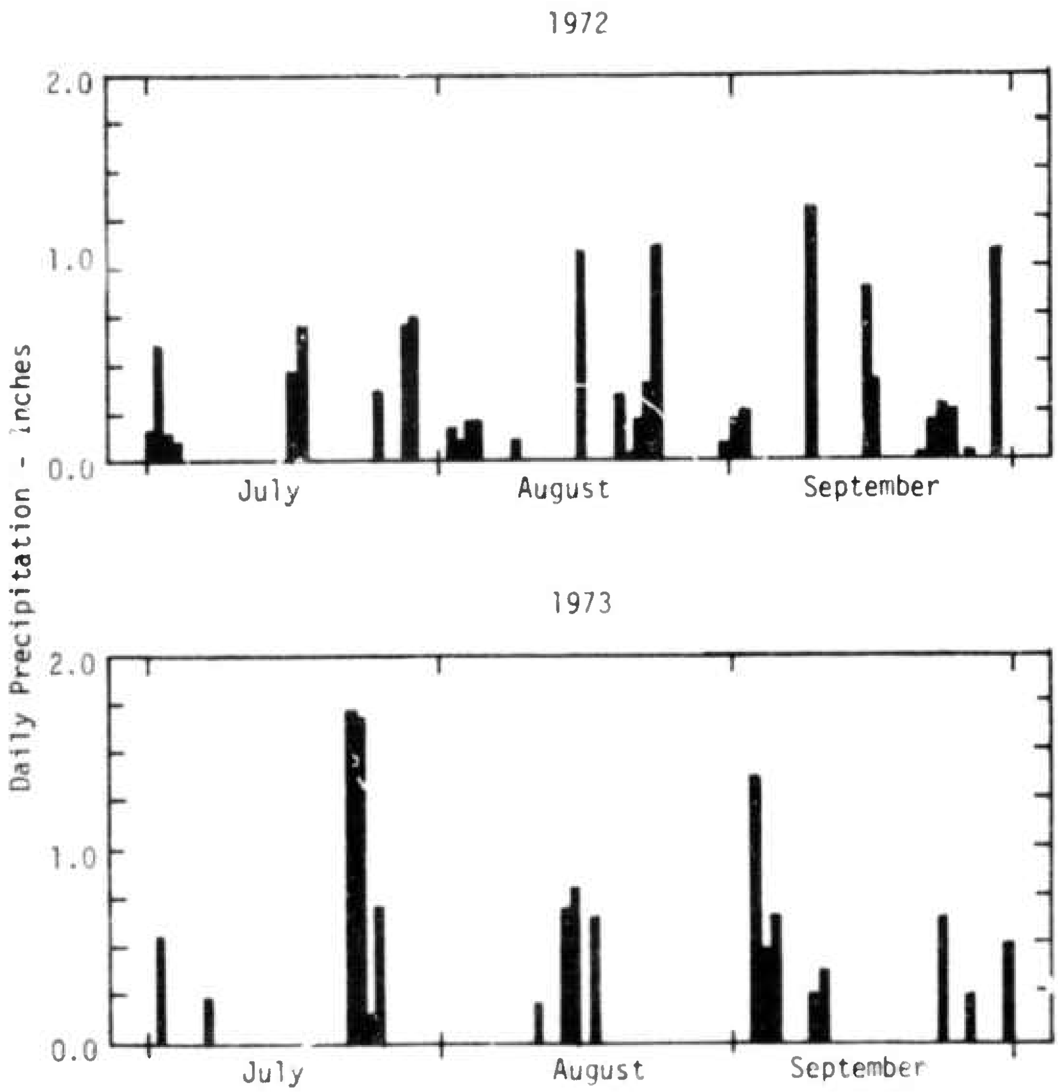


FIGURE F-III (continued)

PATTERNS OF PRECIPITATION AT ROLLA, MISSOURI, FOR THE MONTHS OF JULY, AUGUST, AND SEPTEMBER IN THE YEARS FROM 1970 TO 1973



Source: Reference 5.

The Georgia site in Table F-I, from which the sycamore yield data to be used in this analysis were collected, is an upland site where the soils are a mixture of clay and clay loam, and the site index for pine in natural stands is about eighty[7,8]. Having regard for the higher soil moisture availability requirements of oak than of pine, the index for oak in natural stands at the Georgia site is probably about seventy-five. This value is at the higher end of the range of site indices for oak in natural stands in the vicinity of Fort Leonard Wood. Moreover, the soils at the Georgia site, being clay and clay loam, are expected to have a higher moisture retention capacity than the cherty Clarksville soils in central Missouri, and as a consequence, sycamore yields are likely to be ten to fifteen percent lower at the better sites on and near Fort Leonard Wood than at Athens, Georgia[3].

A comparison between the soils of the Clarksville series around Fort Leonard Wood and the bottomland sandy loam at Milford (which is near Manhattan, Kansas) where the experimental yield data for Sioux and Missouri cottonwood were collected[9] is shown in Table F-IV. The differences in organic content and plant-nutrient level are not important because fertilization and other soil management techniques in Energy Plantation operation will compensate for these factors. Differences in pH are also relatively unimportant as they can be compensated or plant species suitable for mildly acid soils can be selected for plantation culture. The moisture capacity of the soils is slightly larger at the Kansas site than at the Missouri one, but the difference is probably not sufficient to cause significant differences in productivity between the two sites.

The soil permeabilities at the two sites are significantly different. On the basis of the higher permeability of the soil at Milford than at Fort Leonard Wood, a much larger fraction of the rainfall can be expected to be

TABLE F-III

PRECIPITATION AT ROLLA, MISSOURI, AND EVAPORATION AT LAKEVIEW, MISSOURI, IN JULY, AUGUST AND SEPTEMBER FOR THE YEARS 1970 TO 1973*

	July		August		September	
	Precip. Inches	Evap. Inches	Precip. Inches	Evap. Inches	Precip. Inches	Evap. Inches
1973	5.02	6.93	2.37	6.55	4.35	3.75
1972	3.90	6.07	3.95	5.94	4.89	4.03
1971	2.45	6.67	0.63	6.18	2.69	4.49
1970	1.14	6.93	1.88	6.12	5.16	3.35

---

*The evaporation data must be interpreted with caution because they are for evaporation from water surfaces. They are not for evaporation from the soil.

Source: Reference 5.

absorbed by the Milford soil than by the Fort Leonard Wood soil. But as already noted for the two sites, rainfall in the latter part of the summer and early fall consists of relatively infrequent heavy downpours. It is expected, therefore, that the higher soil permeability at Milford will allow a larger fraction of the rainfall to be stored as soil moisture there, than at Fort Leonard Wood and its environs. As a consequence, the soil moisture supply at Milford is likely to be better able to carry deciduous species through dry spells without significant detrimental effect on plant-material yield than at Fort Leonard Wood. Indeed, inspection of the experimental plantations at Milford and Tuttle, Kansas, during the drought in the summer of 1974 showed that most of the varieties tested (silver maple and plains cottonwood, in particular) did not display any wilting, while other crop varieties, such as corn, growing in neighboring fields had already reached the stage of "browning" of the leaves.

On the basis of the comparisons between the vicinities of Manhattan, Kansas, and Fort Leonard Wood, it is concluded that yields from deciduous species at Fort Leonard Wood will probably be about fifteen percent lower than yields for the same species grown at the Milford site near Manhattan, Kansas. This opinion is shared by Professor Wayne A. Geyer, who is responsible for the experimental programs with deciduous species at the Kansas sites--in fact, he estimates that the differences in productivity might be as much as twenty-five percent. The Mississippi experiments on cottonwood[11] were conducted on alluvial silt loam soil. No detailed description of the soil and soil-moisture characteristics at the experiment site are available, but the site is in a region where cash crops are regularly produced and where water is in abundant supply through rainfall, streamflow and ground water[12]. On this basis, it is estimated that the yields for cottonwood will be about thirty percent lower at Fort Leonard Wood than at the Mississippi site where the yield data were collected.

TABLE F-IV

COMPARISON OF SOIL CHARACTERISTICS OF THE CLARKSVILLE (SLOPING HILLS) SOILS AROUND FORT LEONARD WOOD AND THE MILFORD SANDY LOAM BOTTOMLAND SITE NEAR MANHATTAN, KANSAS

Soil Characteristic	Fort Leonard Wood	Milford, Kansas
pH	5.3 - 6.5	7.4 - 7.8
Moisture Capacity, percent	10	11.8
Organic Matter, percent[1]	4.8	0.4 - 0.8
Available Phosphorus, lb per acre[1]	38	14 - 80
Exchangable Potassium, lb per acre[1]	≈ 200	198 - 447
Permeability, inches per hour[2]	2.5 - 5.0	$\gtrsim$ 10

Footnotes:

1. For the top eight inches of the soil layer.
2. For the top twenty inches of the soil layer.

Sources: Fort Leonard Wood data - Reference 3.
Milford, Kansas data - Reference 10.

Moreover, the climatic comparison for these two sites (see Table F-II) also suggests a somewhat lower production potential at the fort than at the Mississippi site.

III. CHOICE OF SPECIES FOR ENERGY PLANTATIONS AROUND FORT LEONARD WOOD

A selection of deciduous plant species recommended for Energy Plantations in the Fort Leonard Wood area is presented in Table F-V. This selection is made on the basis of the data collected during site visits in Pennsylvania, Iowa, Kansas, Georgia and Fort Leonard Wood, and from a number of experts including several with intimate familiarity with the Fort Leonard Wood area.

In the case of the sloping hill sites, the most sirable species are varieties of hybrid poplar and plains cottonwood. Good prospects are offered also by drought-resistant varieties of eastern cottonwood, sycamore and silver and red maple, while European black alder and Ailanthus (tree-of-heaven) should be considered. European black alder has a number of attractive characteristics, including being a legume, while Ailanthus grows profusely--almost as a weed in the Fort Leonard Wood area. Qualitative data indicate that both these species are fast juvenile growers although it is not known whether Ailanthus can be started from clones. The choice of species for bottomland culture includes eastern cottonwood, sycamore, silver maple and various hybrid poplars.

The hybrid poplars specially suited for sloping hill sites are shown in Table F-VI, where the genesis of the recommended varieties is also shown.

TABLE F-V

DECIDUOUS SPECIES RECOMMENDED FOR ENERGY PLANTATIONS AT FORT LEONARD WOOD

Suitability Ranking	Species	Comments
For Sloping Hill Sites:		
Highly recommended	Hybrid poplars	See Table F-VI.
	Plains cottonwoods	Sioux male and Missouri varieties, for instance
Good prospects	Eastern cottonwood	Drought-resistant varieties
	Silver maple	" " "
	Red maple	" " "
	Sycamore	Assuming adequately drought-resistant varieties exist
Worth consideration	European black alder	Suitable for acid soils, fixes nitrogen, fast juvenile grower and many varieties available
	Ailanthus (tree-of-heaven)	Grows like a weed in vicinity of the fort - fast juvenile grower, but may not be reproducible from clones.
For Bottomland Sites:		
Highly recommended	Eastern cottonwood Hybrid poplars Silver maple Sycamore	Periodic flooding may be a problem for all these.

Preceding page blank

TABLE F-VI

CANDIDATE VARIETIES OF HYBRID POPLAR FOR ENERGY PLANTATIONS ON SLOPING HILL SITES AT FORT LEONARD WOOD

Canadian Sources

1. *P. x deltoides* Barti cv. FNS#44-52
2. *P. x deltoides* Barti cv. Northwest
3. *P. x deltoides* Barti cv. Brooks
4. *P. x balsamifera* L. cv. Cordeniensis
5. *P. x laurifolia* Ledeb. cv. Volumteer Kerr.
6. *P. x Petrowskyana* Schneid. var. Dunlop

Midwest Sources

1.	*P. deltoides* x *trichocarpa*	Clone NE-216
2.	*P. deltoides* x cv. Caudina	Clone NE-222
3.	*P. deltoides* x cv. Caudina	Clone NE-228
4.	*P. deltoides* x cv. Caudina	Clone NE-355
5.	*P.* cv. Betulifolia x *trichocarpa*	Clone NE-296
6.	*P.* cv. Betulifolia x *trichocarpa*	Clone NE-300
7.	*P.* cv. Angulata x *deltoides*	Clone NE-245

Northeastern Sources

1.	*P. deltoides* x cv. Caudina	Clone NE-224
2.	*P. deltoides* x cv. Caudina	Clone NE-225
3.	*P. deltoides* x cv. Caudina	Clone NE-226
4.	*P. deltoides* x *trichocarpa*	Clone NE-350
5.	*P. deltoides* x *trichocarpa*	Clone NE-207
6.	*P.* cv. Angulata x *trichocarpa*	Clone NE-252
7.	*P.* cv. Charkowiensis x cv. Caudina	Clone NE-311
8.	*P.* cv. CHarkowiensis x cv. Caudina	Clone NE-312
9.	*P.* cv. Charkowiensis x cv. Caudina	Clone NE-316
10.	*P.* cv. Charkowiensis x cv. Caudina	Clone NE- 21
11.	*P.* cv. Charkowiensis x cv. Berolinensis	Clone NE- 26

IV. PREDICTED YIELDS AND SUGGESTED HARVEST SCHEDULES

Average annual sustained yield optimization calculations for the species of interest in the Fort Leonard Wood area are described in section VIII of Appendix C. The calculations have been made on the basis of data collected at several locations, none of which is in the vicinity of Fort Leonard Wood. Consequently, it is necessary to take account of differences in the climate and soil character between the Fort Leonard Wood area and the sites at which the yield data were collected. These adjustments are based on the analysis presented in section II of this appendix. The resulting yield estimates from a number of species are shown in Table F-VII, along with the planting densities and harvest schedules required for achieving the estimated yields.

For its proper understanding and interpretation, the information in Table F-VII requires explanation. The first column is a list of the species considered in the optimization calculations in section VIII of Appendix C. The group of three columns under the general heading "Adjustment - %" describes the nature and amount of adjustments made to the original optimization estimates generated in Table C-XXIX in Appendix C, in order to predict yields at the Fort Leonard Wood region. The adjustments are expressed as percentages of the estimated yields shown in Table C-XXIX. The "base" adjustment takes into account the fact that in some cases, the estimates in Table C-XXIX are thought to be too high or too low because of recognized uncertainties in the parameters used in making the estimates. The second and third columns under the adjustment heading give the minimum and maximum adjustments applied to take into account the differences in estimated productivity between the Fort Leonard Wood area and the sites at which yield data were collected. These adjustments take into account the growth potential estimates from climatic data as described in Table F-II and the expected differences in yields estimated on the basis of moisture availability as discussed in section II.C. For instance, in the case of hybrid poplar, in

TABLE F-VII

PREDICTED YIELDS FROM VARIOUS DECIDUOUS SPECIES AND CORRESPONDING PLANTING DENSITIES AND HARVEST SCHEDULES FOR FORT LEONARD WOOD AND VICINITY*

Species	Adjustment, % Base	Min.	Max.	Planting Area Ft^2 Per Plant	Stand Age At First Harvest - Years	Interval Between Harvests - Years	Estimated Average Annual Yield Tons (Oven-Dry) per Acre-Year
Hybrid Poplars	-	-4	-15	4	1	2	8.3 to 9.4
				4	2	2	7.6 to 8.6
				6	1	2	7.4 to 8.4
Eastern Cottonwood:							
High estimate	-	-30	-38	4	1	3	8.5 to 9.7
				4	1	2	8.1 to 9.3
				4	2	3	7.0 to 8.0
Eastern Cottonwood:							
Low estimate	-	-30	-38	4	1	3	5.7 to 6.5
				4	1	3	5.4 to 6.2
				4	2	3	4.7 to 5.3
Missouri Cottonwood (Milford Site)	-4	+16	+2	4	1	2	10.8 to 12.3
				6	1	3	10.3 to 11.7
				4	2	2	9.5 to 10.8
Sioux Cottonwood (Milford Site)	-	+16	+2	4	1	2	15.1 to 17.1
				6	1	2	14.5 to 16.4
				6	2	2	13.6 to 15.4
Silver Maple (Milford Site)	-5	+16	+2	4	1	3	7.2 to 8.2
				6	1	4	7.0 to 8.0
				4	2	3	6.6 to 7.5

TABLE F-VII (continued)

PREDICTED YIELDS FROM VARIOUS DECIDUOUS SPECIES AND CORRESPONDING PLANTING DENSITIES AND HARVEST SCHEDULES FOR FORT LEONARD WOOD AND VICINITY*

Species	Base	Min.	Max.	Planting Area Ft^2 Per Plant	Stand Age At First Harvest - Years	Interval Between Harvests - Years	Estimated Average Annual Yield Tons (Oven-Dry) per Acre-Year
Sycamore:							
Low estimate	-1	-11	-16	20	1	3	5.0 to 5.3
				18	1	3	4.9 to 5.2
				20	2	3	4.6 to 4.9
High estimate	-	-11	-16	4	1	3	9.7 to 10.3
				6	1	3	9.6 to 10.2
				8	2	3	8.5 to 9.0

* See text for an explanation of the basis for the average annual yield estimates shown in this table and the appropriate interpretation of the estimates.

accordance with the estimates in Table F-II, the estimated yields in Table C-XXIX have been multiplied by 1.13 to take into account the more favorable insolation and temperature conditions. Then, the values so obtained were decreased by fifteen percent (minimum adjustment) and 25 percent (maximum adjustment[6]) to take into account the difference in soil moisture availability between State College, Pennsylvania and Fort Leonard Wood as discussed in section II.C. of this appendix. The net adjustments are -4% and -15% as indicated in Table F-VII. The last four references are the planting area per plant and harvest schedule combination, which is expected to produce the average annual sustained yield in the Fort Leonard Wood area shown in the right hand column. The same three optimizations are shown in Table F-VII as are shown in Table C-XXIX, namely the planting density-harvest schedule combination which produces the highest estimated yield per acre-year at Fort Leonard Wood, the combination which produces the second highest yield, and the combination which produces the highest yield when the first harvest is taken when the stand is two years old. In one instance, this latter schedule also produces the second highest estimated yield.

The hybrid poplar estimates are based on the results for the highest yielding clone at Stone Valley, Pennsylvania[6], namely clone NE-388. It is assumed that clones with comparable productivity are available for the Fort Leonard Wood area.

For eastern cottonwood, the estimated growth potential (see Table F-II) is lower at Fort Leonard Wood than at the Mississippi site for which yield data are available[11]. Moreover, the difference in moisture availability between the two sites suggests a further reduction in yield of from twenty to thirty percent, for a combined reduction in yield from thirty to thirty-eight percent at Fort Leonard Wood compared with the Mississippi site.

The growth potential at Fort Leonard Wood is significantly larger than that at the Kansas sites (see Table F-II). Of the two Kansas sites, only data from the Milford site have been considered because the soils there are more nearly similar to those at Fort Leonard Wood. In the case of Missouri cottonwood, a base adjustment of four percent has first been applied as suggested by the results shown in Table C-XXIII. The combined positive adjustment (better growth potential) and negative adjustment of fifteen and twenty-five percent due to the available soil moisture pattern results in net positive adjustments of sixteen and two percent. The same adjustments are used for Sioux cottonwood with the exception of the base adjustment.

The growth potential for the Fort Leonard Wood and Georgia sites are very similar (see Table F-II) while it is estimated that available moisture would reduce the yields by ten to fifteen percent at the Missouri site (section II.C. of this appendix).

The estimates in Table F-VII are summarized as follows:

- the optimum planting areas per plant range between four and eight square feet per plant and depend on species;
- the optimum harvest schedule generally consists of a first harvest when the stand is a year old, and subsequent harvests at two or three-year intervals; and
- the maximum average predicted annual yield is of the order of eight oven-dry tons per acre-year with a range extending from about seven to about nine or possibly nine and a half dry tons per acre-year.

The predicted yields for the Missouri and Sioux cottonwoods are too high to be believed. Such yields do not appear to have been achieved even in nurseries where the greatest care has been exercised. Moreover, the experimental yields for these varieties of cottonwood and silver maple from the same site in Kansas are of the same order of magnitude for the three species, all other things being equal. It is probably reasonable, therefore, to assume that these cottonwood varieties will have predicted yields at Fort Leonard Wood comparable or slightly higher than those predicted for silver maple at the fort--that is, between about seven and eight oven-dry tons per acre-year.

V. OPERATIONAL DATA FOR ENERGY PLANTATIONS AT FORT LEONARD WOOD

V.A. Introduction. The total fuel consumption in fiscal year 1973 at Fort Leonard Wood was 2.1×10^{12} Btu (see Table A-VII). If this energy is to be supplied by SNG produced from plant material grown in an Energy Plantation, about 240,000 tons (oven-dry basis) will be required annually, assuming that about 4.45 standard cubic feet of SNG are produced per pound (oven-dry basis) of plant material. If the plant material grown in the plantation is to be used as a solid fuel at the fort, about 180,000 tons (oven-dry basis) will be needed to provide the equivalent of 2.1×10^{12} Btu per year.

V.B. Operational Data for an Energy Plantation. Most of the basic information on field machinery operation, manpower requirements and unit costs used for defining plantation operation has been compiled by Opekasit, Inc.[13], agricultural engineering consultants to InterTechnology.

V.B.1. General Organization of the Energy Plantation. To achieve adequate supervision and good labor and field machinery utilization, the field production of chipped plant material (solid fuel or raw material for SNG production) will be done by operating units designed to produce 40,000 tons (oven-dry basis) per year of chipped plant material delivered five miles from the plantation.

Each plantation operating unit will be a separate production unit, except that it will share equipment maintenance facilities (the motor pool), clone production and storage facilities and supervision with other similar operating units at Fort Leonard Wood. Six plantation operating units will be required if SNG is to be produced from plant material at Fort Leonard Wood, and four and a half units will be needed if the plant material is to be used as solid fuel.

V.B.2. Supervisory Team. For an Energy Plantation producing either solid fuel or raw material for SNG production at Fort Leonard Wood, the following supervisory team will be required:

- one general foreman with overall responsibility for all plantation operations, including delivery of harvested plant material to its point of use on the base and return of residues from that point to the plantation;
- one assistant or field foreman,
- one horticulturist with responsibility for clone collection, clone planting and staff responsibility for maintaining the plant-material productivity of the plantation;
- one motor pool foreman with responsibility for maintaining and servicing field equipment; and
- one secretary-dispatcher.

The supervisory team will have four pickup trucks at its disposal.

V.B.3. Operational Data for a 40,000-Ton-Per-Year Plantation Production Unit. As much as is practical, a plantation production unit will have the configuration of a square or rectangle with rows running the longest dimension. Some field roads will be necessary to minimize damage from compaction, "rutting" when soft, or damage to small, young growth or recently harvested stumps.

V.B.3.a. Plantation Production Unit Area. The operational data for a plantation production unit, such as the area planted and its area harvested per year, will depend on the planting density and harvest schedules adopted for the plantation.

Consider a plantation production unit with a planting area per plant A square feet, first harvest taken when stands are n_1 years old, subsequent harvests taken at intervals of n_2 years thereafter, and a total of m subsequent harvests before stands are replanted. A value of five is assumed for m because there are data available which show that a total of at least six harvests can be taken from a stand (see Appendix C, section IV.A.8.) without impairing its annual average sustained yield.

Each plantation production unit is divided in $n_1 + m \times n_2$ equal planting areas. Each planting area is harvested for the first time after n_1 years and then m times at n_2-year intervals. After a completed cycle ($n_1 + m \times n_2$ years), each planting area is cleared and replanted. The situation for a 1 + 5 x 3 harvest schedule is illustrated in Figure F-IV. The area a acres of the individual planting areas is chosen so that the total annual harvest from the plantation production unit is 40,000 tons (oven-dry basis) of plant material plus the clones needed to replant one planting area of a acres.

The total number of clones needed to replant a planting area of a acres is:

$$\text{Total clones} = \frac{43,560}{A} \times a \qquad \text{(F-1)}$$

Assuming that the planting area being harvested for the first time is used to generate the planting material, the number of clones produced per acre is

$$\text{Clones per acre} = c \times N_{n_1} \qquad \text{(F-2)}$$

where c is the number of clones collected per plant, and N_{n_1} is the number of plants surviving at year n_1 per acre.

Planting material is collected from the first harvest from a planting area to avoid possible genetic degeneration which could occur if planting material is collected from older stands having been harvested several times.

The area needed to supply the total number of clones per year needed for replanting is derived from equations F-1 and F-2, and is:

area needed to supply clones required per year =

$$\left(\frac{a}{cN_{n_1}}\right) \left(\frac{43,560}{A}\right) \qquad \text{(F-3)}$$

The effective yield of plant material from the planting area being harvested for the first time is:

$$aY_{n_1} \left(1 - \frac{43,560}{cN_{n_1} A}\right) \qquad \text{(F-4)}$$

where Y_{n_1} is the total tonnage (oven-dry basis) harvested per acre from the planting area.

The area a acres of a planting area is:

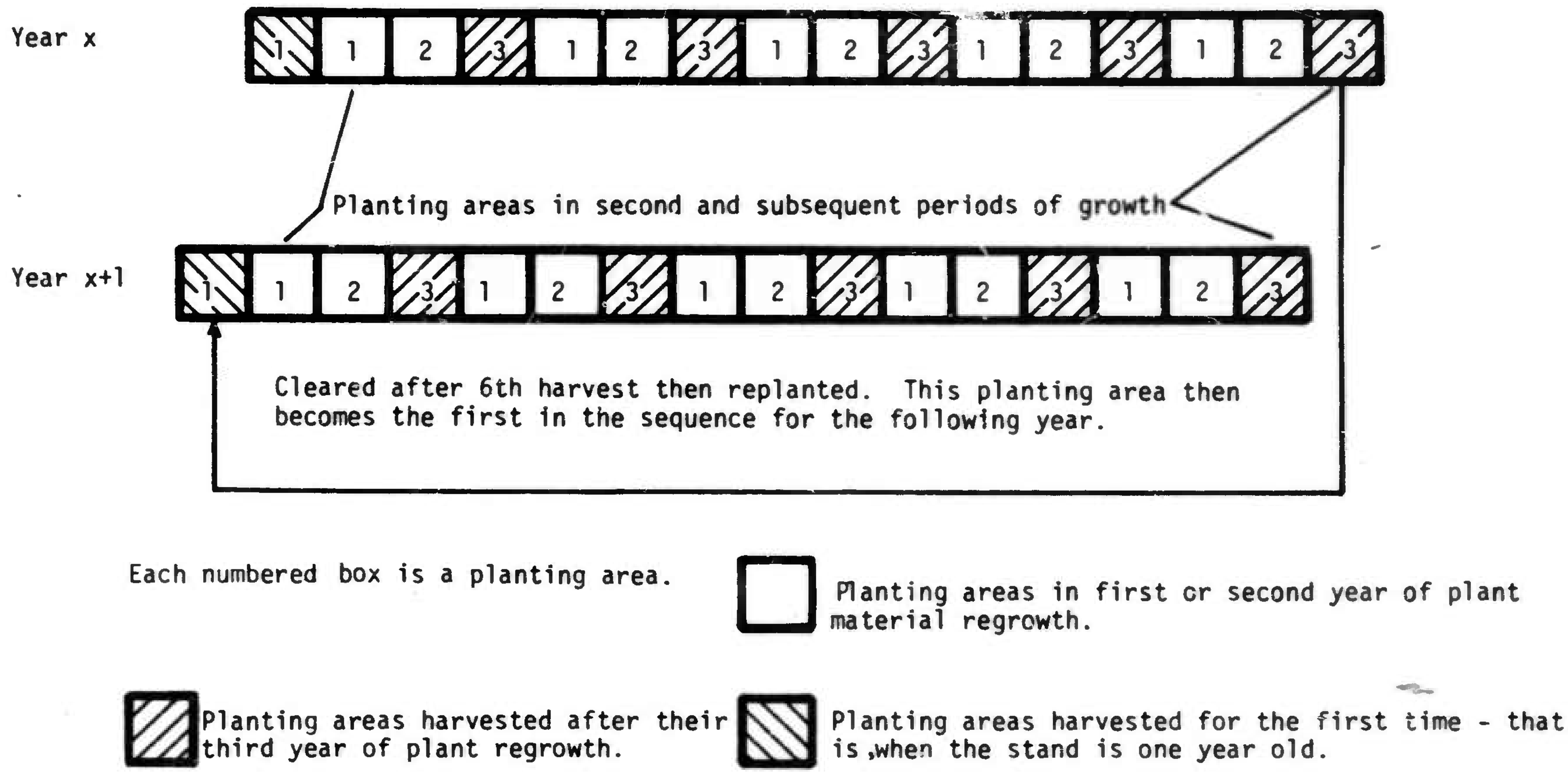
$$a \left[m \times Y_{n_2} + Y_{n_1} \left(1 - \frac{43,560}{cN_{n_1} A}\right)\right] = 40,000 \text{ tons (oven-dry basis)} \qquad \text{(F-5)}$$

where Y_{n_2} is the total tonnage (oven-dry basis) from harvests after the first harvest per acre.

he total area of the plantation production unit is $(n_1 + m \times n_2)a$ and the area harvested every year is $(m + 1) \times a$.

FIGURE F-IV

ARRANGEMENT OF PLANTING AREAS FOR A PLANTATION PRODUCTION UNIT ON A 1+5x3 HARVEST SCHEDULE



Thus, given a harvest schedule, planting density, stand age at first harvest and intervals between subsequent harvests, equation F-5 determines the area of the plantation production unit having an annual capacity of 40,000 tons (oven-dry basis) per year.

V.B.3.b. Field Operations for a Plantation Production Unit. The yearly schedule and associated equipment and manpower required for the field operations in a plantation production unit are discussed in this section and summarized in Table F-VIII. Production is based on 230 work days annually when fields are fit to work. This leaves approximately 30 work days for other miscellaneous work, vacations and any other minor jobs not otherwise specifically described. The work week is five days of ten hours each, with only nine productive hours per day. This work schedule conforms with general practice in large farming operations[13].

V.B.3.b.(i). Chip Harvesting. This operation is pursued year long at a continuous rate of about [(m+1) a/12] acres being harvested monthly. Although the fuel demand is not uniform over the year (see Appendix A), continuous field operation is preferred as a harvesting schedule linked to fuel demand would require a larger field equipment capacity which would only be used fully during a few winter months.

It is assumed that a double-row harvester will chip eight tons of green chips per hour, or about four tons (oven-dry basis). This production has been verified with chipper manufacturers as being reasonable[13]. This harvesting rate is assumed to be limited only by the amount of material harvested and not by the acreage involved; thus, the equipment and manpower required may be considered constant for all planting densities and harvest schedules considered. On the basis of 230 work days per year, harvesting will require five harvesters per plantation production unit.

TABLE F-VIII

FIELD OPERATION SCHEDULE FOR A PLANTATION PRODUCTION UNIT HAVING A CAPACITY OF 40,000 TONS (OVEN-DRY BASIS) PER YEAR

Operation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chip Harvesting - 5 harvesters - (m+1) xa acres per year	———	———	———	———	———	———	———	———	———	———	———	———
Chip Hauling - 5 trucks - 7 dumpwagons - 2 tractors	———	———	———	———	———	———	———	———	———	———	———	———
Sludge Hauling[1] - 4 sludge trucks (m+1) xa acres per year	———	———	———	———	———	———	———	———	———	———	———	———
Fertilizer Spreading - sidedresser + tractor $189.6A^{-2.015} \times n_2 \times y_{n_2}$ on (m+1) xa acres per year	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Land Clearing - a acres per year - 1/4 crawler tractor	-------	-------	-------									
Planting Unit - a acres per year - tractor + 2 row planter				-------	-------	-------						
Cultivation - [3 + 1.25 (m+1)] xa acres per year - tractor + 4 row cultivator				-------	-------	-------	-------	-------	-------			
Fungicide - (m+1) xa/4 acres per year - tractor + sprayer						-------	-------	-------				

Footnotes: 1: Only for plantation production units producing raw material for SNG production. For plantation production units producing solid fuel, the ash will be returned to the plantation in chip hauling trucks.

Legend:

——— full-time operations underway throughout every working day.

------- part-time operations not requiring full-time every working day or not undertaken throughout the year.

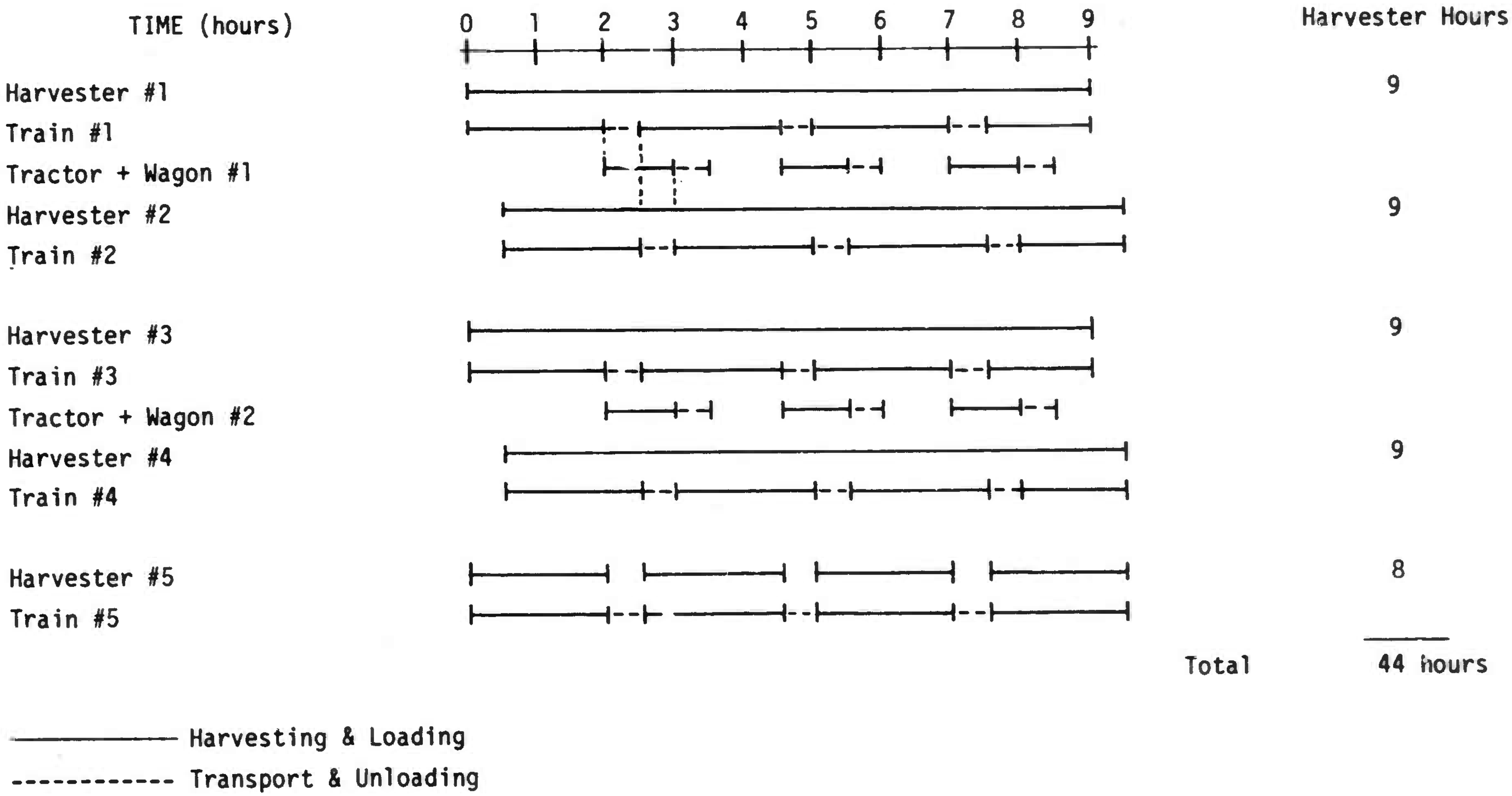
V.B.3.b.(ii) Chip Hauling. The harvester-chipper is followed in the field by a chip-hauling truck pulling a dumpwagon. The total capacity of the train is eight tons (oven-dry basis). Every two hours, the train (truck plus wagon) is driven to the processing plant (SNG production) or storage area (solid fuel) where it is unloaded. The train then returns to the field. It is assumed that the round trip requires about a half hour (approximately five miles one way at about thirty miles per hour plus unloading time). To ensure continuous operation, and thus to ensure the daily production capacity required to harvest 40,000 tons per year, it is necessary to provide several truck-and-wagon units.

An illustrative working schedule and equipment requirement is shown in Figure F-V. To harvest 40,000 tons per year, it is necessary to harvest about 174 tons per working day, which is the equivalent of about 43.5 hours of harvester time per day. Harvester #1 works continuously from hour 0 to hour 9. At hour 2, when train #1 (truck plus dumpwagon) is full, the train goes to the central delivery point and a tractor pulling a dumpwagon takes over the chip collection. If harvester #2 starts in the morning half an hour later than #1 does, the train #2 will be filled when train #1 returns. At that point, the tractor-dumpwagon combination #1, which is half full by then, is free to collect chips from harvester #2 while its train (#2) goes to the delivery point. In this fashion, both harvesters work a full nine hours. The same schedule is applied to harvesters #3 and 4. The schedule of harvester #5 is lengthened by half an hour to reach a total of 44 harvesting hours per day.

V.B.3.b.(iii) Sludge Hauling and Spreading. When the plant material is used for making SNG, about 58,000 tons (wet basis) of sludge are produced per year per 40,000 tons (oven-dry basis) of plant material converted to

FIGURE F-V

HARVESTING AND CHIP-HAULING SCHEDULES



SNG. The sludge is spread on the area harvested during the year, that is on (m+1)xa acres. Assuming a time of one hour and twenty minutes for loading, spreading and traveling (ten miles round trip), four ten-ton sludge trucks are required. It will be assumed as a first approximation that this operation is essentially independent of the acreage involved.

<u>V.B.3.b.(iv). Fertilizer Spreading</u>. When the plant material from the plantation is used as solid fuel, fertilizer (mostly nitrogen-see Appendix C, section VII) has to be applied to the land in the plantation. Fertilizer is applied to the land after harvesting during the year in which the harvesting occured, and therefore (m+1)xa acres are fertilized every year.

Based on data from Opekasit[13], a two-row sidedresser pulled by a tractor can fertilize 288 acres per month, which means that this equipment will also have time available for spreading ash on the land if the harvest of the plantation is used as solid fuel.

<u>V.B.3.b.(v). Road Work and Land Clearing for Replanting</u>. Every year, one planting area is cleared and replanted per plantation production unit. It is estimated[13,14] that a crawler tractor of the type generally used for land clearing can clear about 325 acres per month. Thus, one such tractor would be sufficient for clearing a planting area in each of as many as four plantation production units per year and still have about half a year available for road work and the like on the plantation.

<u>V.B.3.b.(vi). Planting</u>. Each year, one planting area in a plantation production unit is replanted. It is estimated by Opekasit[13] that a tractor with a two-row planter can plant about 36,000 clones per day, or the equivalent

of about three acres per day at a planting density of four square feet per plant.

V.B.3.b.(vii) Cultivation. Cultivation for weed control is necessary during the first growing season after a planting area has been replanted (see Appendix C, sections IV.A.5. and IV.A.6.c.). It is estimated that three cultivations will be needed during the summer and fall after replanting. The total area to be cultivated after replanting is 3a acres.

Depending on the time of the year when a planting area is harvested, it will need one or two cultivations. It is expected that those areas harvested between August and the following April will require one cultivation and those harvested in May, June and July will require two. The total area every year to be cultivated after harvesting is estimated therefore to be fifteen times the area harvested per month.

The total area to be cultivated every year per plantation production unit is therefore:

$$[3 + \frac{15}{12}(m+1)]\times a = [3 + 1.25\,(m+1)]\times a \qquad \text{(F-6)}$$

A tractor with a four-row cultivator can cultivate about 760 acres per month[13].

V.B.3.b.(viii). Fungicide Application. Fungicide application is recommended[13] on the areas harvested during the summer months to prevent deterioration of the freshly cut stump. It is proposed to apply fungicide on the areas harvested in May, June and July, which is an area equal to $0.25a\times(m+1)$ acres. The fungicide will be applied during the months of June, July and August. A tractor and sprayer can apply fungicide to 760 acres per month.

V.B.3.b.(ix). Lime Application. The soil in deciduous-species plantations is likely to become increasingly acid at many sites as a result of deterioration of plant litter at the soil surface. The harvestable yield from most species recommended for plantation culture is sensitive to the pH of the soil. It will be necessary, therefore, to apply lime from time to time to the soil. It is estimated that about half a ton of agricultural limestone per acre will be sufficient if it is applied shortly after harvesting. Thus, lime will have to be applied to (m+1)a acres per year. It is assumed that the application is made by custom contractors at a cost of ten dollars per acre for the lime and its application to the ground.

V.B.3.c. Clone Production. As previously noted, clones will be collected from the first harvest from a stand. Clone production involves collecting stems from the plants, cutting them into clone lengths (ten to twenty inches, depending on species) and discarding material having a diameter less than about a quarter inch. The discarded material will be chipped and added to the regularly harvested and chipped plant material from the stand. Clone collection will be carried out in the fall and early winter after the plants have gone dormant for the winter.

The clones will be packed in moist sawdust in cartons and stored for about three months in storage cellars at the plantation. The cellars will be built below the frost line where the temperature will be cool enough to allow the clones to mature and be ready for planting in the following spring.

The harvesters will be used for stem harvesting, the stems bypassing their chippers. The stems will be brought to a central location in the plantation where they will be cut into clones and packed for storage.

It is assumed that c clones can be cut from a plant, and that a man can handle the material from twelve plants every two minutes using a chain saw which means that he will produce 360c clones per hour. In a nine-hour day, production will be about 3240c clones per man-day. To achieve this rate of production, each cutter is assisted by two helpers; one of whom handles, bundles and delivers the stems to the cutter, while the other is responsible for packing and storing the clones. It is thus estimated that 3240c clones are produced by a three-man team per day.

V.B.3.d. Motor Pool. This function is charged with responsibility for maintaining, repairing and servicing field machinery, trucks and other equipment used at the plantation. The motor pool will be assigned back-up equipment for use as replacements for field machinery, trucks and other equipment withdrawn from service for maintenance or repair. The size of the back-up equipment pool will depend on the amount of equipment at the plantation. Maintenance and repair will be done in a suitably equipped building on the plantation. Office space for the supervisory force and a storeroom will also be provided in the building.

V.B.3.e. Plantation Machinery Costs. Capital and maintenance costs, fuel requirements and expected service lives for the various types of major equipment used in the plantation are shown in Table F-IX. These data, compiled by Opekasit[13], are used for estimating the cost of establishing a plantation and for estimating operating costs.

V.B.3.f. Plantation Personnel Pay Rates. The estimated pay rates, by skill level, for plantation personnel are shown in Table F-X.

V.C. Cost of Plant-Material Production From an Energy Plantation in the Fort Leonard Wood Area.

V.C.1. Introduction. As shown in Table F-VII, maximum yields per acre-year are generally obtained with a 4-1-2 planting-harvest cycle combination. This combination will be adopted for the present discussion. Three levels of productivity will be considered--an average annual sustained yield of about 7.4 tons (oven-dry basis) per acre-year (low productivity), about 8.3 tons per acre-year (medium productivity) and about 9.2 tons per acre-year (high productivity). The general description of plantation operations in section V.B. will be followed.

As noted in section V.A., an Energy Plantation for Fort Leonard Wood consists of six plantation production units for SNG production and four and one half for solid-fuel production. The following discussion will deal with one plantation production unit having a yearly capacity of 40,000 tons (oven-dry basis).

V.C.2. Plantation Operational Data.

V.C.2.a. Plantation Size and Characteristics. The basic characteristics of a plantation production unit having a capacity of 40,000 tons (oven-dry basis) per year operated on a 4-1-2 planting density-harvest schedule combination are shown in Table F-XI. The estimates have been generated assuming that hybrid poplar is the species grown. This assumption has bearing on the number of surviving plants as well as on the number of clones which can be produced per plant (clones are usually less than ten inches long for poplars). The area of a planting area has been estimated from equation F-5.

V.C.2.b. Supervisory Team. The annual cost of the supervisory team is shown in Table F-XII. This cost is divided between six plantation production units if raw material for SNG is being grown, and between 4.5 units if solid fuel is being produced.

TABLE F-IX

CAPITAL AND MAINTENANCE COSTS, FUEL REQUIREMENTS AND EXPECTED SERVICE LIVES OF MAJOR EQUIPMENT ON PLANTATIONS

	Capital Cost $/Unit	Maintenance & Repair/Unit-Year $/Year	Fuel Consumption Gallons/Month		Fuel Cost $/Unit-Month	Service Life	Average Replacement Cost-$/Year
			Gasoline	Diesel			
Harvester - two-row	50,000	8,000	-	403	121	5	10,000
Chip Truck	16,700	740	383	-	184	5 - 10	3,170
Dumpwagon	5,000	500	-	-	-	8	625
Sludge Truck	17,500	740	383	-	184	5 - 10	3,250
2630 Tractor	12,000	1,000	-	270	81	6	2,000
Two-Row Tree Planter	1,100	100	-	-	-	15	73
Four-Row Cultivator	2,000	450	-	-	-	5	400
Sidedresser - Two-Row	500	100	-	-	-	5	100
Fungicide Sprayer	2,600	400	-	-	-	5	520
550 Crawler	33,000	6,000	-	949	285	6	5,500
Pickup Truck	5,600	270	192	-	92	5	1,120
Dumpwagon	2,300	75	-	-	-	15	153

Source: Reference 13.

. C.2.c. Field Operations. The field operation schedule is summarized in Table F-XIII for a 40,000-tons-per-year plantation production unit producing raw material for SNG. In this case, sludge from the SNG plant is used as fertilizer. The annual costs associated with this schedule are shown in Table F-XIV. The chip production and hauling, and sludge hauling and spreading schedules and costs are independent of the productivity of the plantation production unit. The other phases and costs of the field operations are adjusted to account for differences in productivity--L being for the lower productivity, M for the middle estimate and H for the higher productivity estimate. The basis for the cost estimates are shown in Tables F-IX and F-X. In the case of the tractor operators for field operations other than chip hauling, the labor cost estimates are made on the basis of one driver full-time (tractor #1) and two drivers half-time (six months) for tractors #2 and #3.

The field operation schedule is summarized in Table F-XV for a 40,000-ton-per-year plantation production unit producing solid fuel. The major difference between this case and that of Table F-XIII is that sludge is replaced by fertilizer. Sludge trucks are thus not necessary while more tractor time is required to spread the fertilizer. The annual costs associated with operations involved in producing solid fuel are shown in Table F-XVI.

V.C.2.d. Clone Production. Clone gathering and storing will be performed during the fall and winter months. Based on the cost estimates shown in Tables F-IX, F-X and F-XI, the anticipated costs for clone production are shown in Table F-XVII. Clone production costs per plantation production unit are the same for producing solid fuel and raw material for SNG.

TABLE F-X

PAY RATES FOR PLANTATION PERSONNEL

Skill Level	$ Per Year	$ Per Month
General Foreman	22,000	
Horticulturist	18,000	
Foreman - Motor Pool	15,000	
Assistant Foreman	11,000	
Secretary - Dispatcher	6,500	
Harvester Operator	9,100	
Truck Driver	7,500	
Tractor Operator	6,500	
Crawler Operator	6,900	
Temporary Help (Planting and Clone Production)	-	450
Mechanic	10,000	

Source: Reference 13.

V.C.2.e. Motor Pool. The capital and operating costs of the motor pool per plantation production unit are shown for plantations producing raw material for SNG in Table F-XVIII, and for solid fuel production in Table F-XIX.

V.C.3. Plantation Establishment. A representative schedule for establishing a plantation production unit covering approximately 5,000 acres is shown in Figure F-VI. As discussed earlier, a production unit is divided into eleven planting areas when the plantation is to be operated on a 1-2 harvest schedule. One planting area is planted during the first year with commercially supplied cones. This area is harvested in the fall or winter between years 1 and 2 to supply the planting material needed in the second year. At the end of years 2 and 3, first harvests will be reaped and the harvested plant material will be spread on the harvested areas as a soil stabilizer and partial fertilizer.

Operational programs based on Figure F-VI, by years, for establishing plantation production units at Fort Leonard Wood with low, medium and high productivities at a planting density of four square feet per plant and for a 1-2 harvest schedule are shown in Table F-XX. Data from Tables F-XI and F-XXI are used for making the estimates shown in Table F-XX. It will be noted that the estimated working rates for some of the machinery shown in Table F-XXI are somewhat different from the rates shown in Table F-IX for the same machinery.

For instance, it is estimated that land clearing for replanting in an established plantation can be accomplished at the rate of about two acres per hour, whereas when clearing the land in preparation for its first use as a plantation, only about an acre and a half can be cleared per hour, because field access lines will not have been established and the vegetation may be more difficult to handle[13,14]. To allow time for establishing field access lanes, culvert construction and other "road work", the time required for the initial land clearing has been increased by ten percent.

TABLE F-XI

CHARACTERISTICS OF A PLANTATION PRODUCTION UNIT AT FORT LEONARD WOOD HAVING AN ANNUAL CAPACITY OF 40,000 TONS (OVEN-DRY BASIS) OF PLANT MATERIAL[1]

Operational Element	Productivity-Tons (o.d.) per Acre-Year		
	7.4	8.3	9.2
Planting area per plant-A (ft^2)	4	4	4
Age at first harvest -n_1 years	1	1	1
Interval between harvests - n_2 years	2	2	2
Yields: First harvest-o.d. T/acre	1.00	1.10	1.20
Subsequent harvests-o.d. T/acre	16	18	20
Average annual-o.d. T/acre-year	7.36	8.28	9.20
Number of clones planted/acre	10,890	10,890	10,890
Number of surviving plants at year 1	10,520	10,520	10,520
Number of harvests after the first-m	5	5	5
Number of clones/plant - c[2]	10	10	10
Area of a planting area - a acres[3]	494	440	396
Area of the Plantation Production unit - acres	5,434	4,840	4,356
Area harvested/year - acres	2,964	2,640	2,376
Number of clones needed/year (thousands)	5,379	4,791	4,312
Area cultivated per year[4] - acres	5,187	4,620	4,158
Tractor-months required for cultivation per year[5]	7	6	5.5
Fungicide application area per year[6] - acres	741	660	594
Tractor-months required per year for fungicide[5]	1	0.9	0.8
Planting-tractor months required[7]	8	7	6.3
Area fertilized per year[8] - acres	2,964	2,640	2,376
Tractor-months for fertilizing per year[9]	10	9	8
Fertilizer required per year - tons[10]	525	525	525
Area limed per year - acres	2,964	2,640	2,376
Lime required yearly[11] - tons	1,482	1,320	1,188
Area cleared for replanting per year - acres	494	440	396
Tractor-months required for clearing	2.6	2.4	2.2
Man-months for clone production per year	26	23	21

1. Based on growing a hybrid poplar well adapted to Fort Leonard Wood.
2. Clones are 4 to 5 inches long.
3. From equation F-5.
4. From equation F-6.
5. Rate: 760 acres/month.
6. See subsection "Fungicide Application" - section V.2.
7. Rate: 36,000 clones/day.
8. See section V.B.3.b.(iv).
9. Rate: 288 acres/month.
10. See section V.B.3.b.(iv).
11. One half ton/acre after each harvest.

Similarly, cultivation for the first time will probably take longer than is expected in established plantations. Three cultivations, rather than two, are provided in the first year following initial clearing to allow for this probability.

Estimated monthly operating costs for plantation establishment work are shown in Table F-XXI. These costs are based in estimates shown in Tables F-IX and F-X.

Estimated costs, by years, for establishing plantation production units at Fort Leonard Wood are shown in Table F-XXII. In making these estimates, it is assumed that the plantation will consist of six production units, and hence have the plant-material production capacity required for meeting the fuel requirement at Fort Leonard Wood with SNG. The costs showr in the table are based on the estimates in Tables F-XX and F-XXI, and are for each of the plantation productivities shown in Table F-XX. The cost estimates in Table F-XXII cover only the work necessary for establishing a production unit--they do not include the capital cost of the machinery, equipment and facilities required.

In making the estimates shown in Table F-XXII, it is assumed that the supervisory staff consists of only the plantation general foreman, horticulturist and secretary-dispatcher during the first eighteen months of the plantation establishment period. The full plantation supervisory staff (see Table F-XII) is assumed beginning in the nineteenth month. Only one mechanic for the entire plantation is assumed to have been hired for the first year. Two are assumed for the second, and three for the third year. The reason for assuming this limited number of mechanics is the presumption that most of the land preparation work will be done by hired custom operators who will be responsible for maintaining their equipment, and that only planting, clone production, and

TABLE F-XII

ESTIMATED ANNUAL COST OF THE SUPERVISORY TEAM*

Cost Element	Annual Cost $/Year
Payroll	
General foreman	22,000
1 Horticulturist	18,000
1 Assistant foreman	11,000
1 Motor pool foreman	15,000
1 Secretary-dispatcher	6,500
Subtotal	72,500
Payroll fringe benefits:	14,500
Maintenance and repair costs:	1,100
Fuel - gasoline:	4,400
Miscellaneous supplies and services:	24,000
Equipment replacement:	4,500
Total Annual Operating Cost:	$121,000

* The annual cost is divided between six plantation production units if raw material for SNG is being produced in the plantation, and between 4.5 units if solid fuel is being grown.

harvesting will be done by the plantation work force. Field equipment therefore will be delivered to the plantation only as the need for these operations develops. Consequently, there will be little of this equipment on hand during the first year and, hence, little demand for maintenance service. More of the equipment will be required in the second year, and still more in the third, which means that the demand for maintenance service will increase as establishment of the plantation progresses. All of the equipment required for plantation operation will have been delivered by the end of the third year.

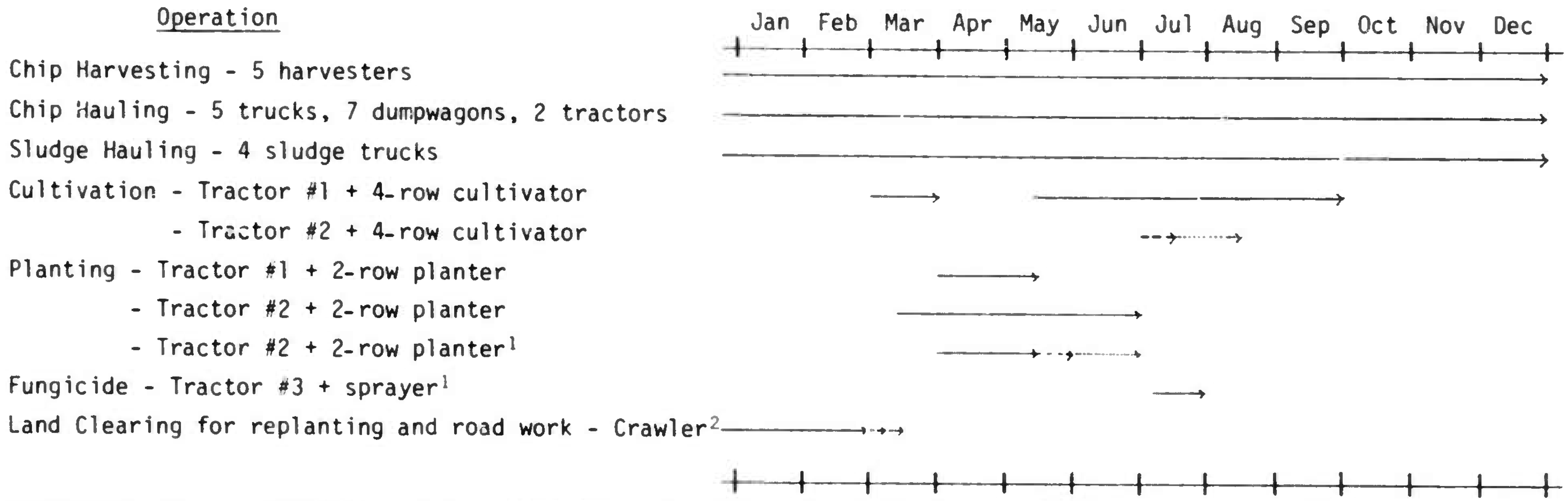
V.C.4. Cost of Energy Plantations for Fort Leonard Wood. The estimated costs of establishing and equipping Energy Plantations at Fort Leonard Wood having an annual capacity of 240,000 tons (oven-dry basis) of plant material for SNG production at three plantation productivity levels are shown in Table F-XXIII. The plantation consists of six plantation production units. The costs incurred in establishing the plantation are based on the estimates shown in Table F-XXII for one plantation production unit. The equipment and facility costs are based on the capital costs per plantation production unit shown in Tables F-XIV, F-XVII and F-XVIII, and on the cost of four pickup trucks (see Table F-IX) required for the supervisory team described in Table F-XII.

The estimated annual costs of operating plantations at each of the three productivity levels are also shown in Table F-XXIII. These operating costs are based on the annual costs per plantation production unit shown in Tables F-XIV, F-XVII and F-XVIII and on the annual cost of the supervisory team shown in Table F-XII. It should be noted that certain costs have not been included in the annual costs, such as return and taxes, which would have to be included if the plantation is operated for the Army by a contractor.

The estimated costs of establishing, equipping and operating plantations producing solid fuel for Fort Leonard Wood at three plantation productivities are

TABLE F-XIII

FIELD OPERATION SCHEDULE FOR 40,000 TONS PER YEAR CAPACITY PLANTATION PRODUCTION UNIT PRODUCING RAW MATERIAL FOR SNG AT FORT LEONARD WOOD



Footnotes:

1. For high-yield plantation production unit, this is shared with another plantation production unit.
2. Shared between four plantation production units.

Legend:

——— for high-yield plantation production units

------ added for medium and low-yield plantation production units

...... added for low-yield plantation production units.

TABLE F-XIV

ESTIMATED CAPITAL AND ANNUAL OPERATING COSTS FOR FIELD OPERATIONS AT A PLANTATION PRODUCTION UNIT AT FORT LEONARD WOOD PRODUCING RAW MATERIAL FOR SNG

Machinery & Supplies		#	Capital Cost $	Maintenance Repair $/Year	Fuel Consumption Gallons/Year		Fuel Cost $/Year	Supplies $/Year	Equipment Replacement $/Year	Payroll[1] $/Year
					Gasoline	Diesel				
Harvesters		5	250,000	40,000	-	24,180	7,260	-	50,000	54,600
Chip trucks		5	83,500	3,700	22,980	-	11,040	-	15,850	45,000
Dumpwagons		7	35,000	3,500	-	-	-	-	4,375	-
Tractors		2	24,000	2,000	-	6,480	1,944	-	4,000	15,600
Sludge trucks		4	70,000	2,960	18,384	-	8,832	-	13,000	36,000
Tractors	L[2]	3	36,000	3,000	-	4,320	1,296	-	6,000	15,600
	M[3]	3	36,000	3,000	-	3,780	1,134	-	6,000	15,600
	H[4]	2.5	30,000	2,500	-	3,402	1,021	-	5,000	13,650
4-row cultivator		2	4,000	900	-	-	-	-	800	-
2-row planter	L	3	3,300	300	-	-	-	-	219	8,640
	M	3	3,300	300	-	-	-	-	219	7,560
	H	2.5	2,750	250	-	-	-	-	183	7,020
Sprayer		1	2,600	400	-	-	-	-	520	-
Crawler	L	0.25	8,250	1,500	-	499	150	-	1,375	2,070
	M	0.25	8,250	1,500	-	461	138	-	1,375	2,070
	H	0.25	8,250	1,500	-	422	127	-	1,375	2,070
Lime[5]	L	-	-	-	-	-	-	14,820	-	-
	M	-	-	-	-	-	-	13,200	-	-
	H	-	-	-	-	-	-	11,880	-	-
Fungicide	L	-	-	-	-	-	-	7,410	-	-
	M	-	-	-	-	-	-	6,600	-	-
	H	-	-	-	-	-	-	5,940	-	-

TABLE F-XIV
(continued)

ESTIMATED CAPITAL AND ANNUAL OPERATING COSTS FOR FIELD OPERATIONS AT A PLANTATION PRODUCTION UNIT

AT FORT LEONARD WOOD PRODUCING RAW MATERIAL FOR SNG

Machinery & Supplies	#	Capital Cost $	Maintenance Repair $/Year	Fuel Consumption Gallons/Year Gasoline	Fuel Consumption Gallons/Year Diesel	Fuel Cost $/Year	Supplies $/Year	Equipment Replacement $/Year	Payroll $/Year
Small tools & general supplies	-	-	-	-	-	-	5,000	-	
Totals L	-	516,650	58,260	41,364	35,479	30,522	27,230	96,139	177,510
M	-	516,650	58,260	41,364	34,901	30,348	24,800	96,139	176,430
H	-	510,100	57,710	41,364	34,484	30,224	22,820	95,103	173,940
Per ton Harvested L	-	-	$1.46	1.03[7]	0.89[7]	$0.76	$0.68	$1.40	$4.44
M	-	-	$1.46	1.03[7]	0.87[7]	$0.76	$0.62	$2.40	$4.41
H	-	-	$1.44	1.03[7]	0.86[7]	$0.76	$0.57	$2.38	$4.35

Footnotes:

1. Including fringe benefits
2. L = low-yield plantation
3. M = medium-yield plantation
4. H = high-yield plantation
5. One half ton per acre at $10 per ton delivered and applied.
6. $10 per acre
7. Gallons per ton of plant material harvested

shown in Table F-XXIV. The capacity of the plantations is 180,000 tons (oven-dry basis) of plant material per year. Four and a half plantation production units are required for this annual production rate.

The plantation establishment costs shown in Table F-XXIV are based on the estimates shown in Table F-XXII for one plantation production unit. The equipment and facility costs are based on the capital costs per plantation production unit shown in Tables F-XVI, F-XVII and F-XIX, and on the cost of four pickup trucks (see Table F-IX) required for the supervisory team described in Table F-XII.

The estimated annual costs of operating plantations at the productivities shown in Table F-XXIV are based on the annual costs per plantation production unit shown in Tables F-XVI, F-XVII and F-XIX, and the annual cost of the supervisory team shown in Table F-XII.

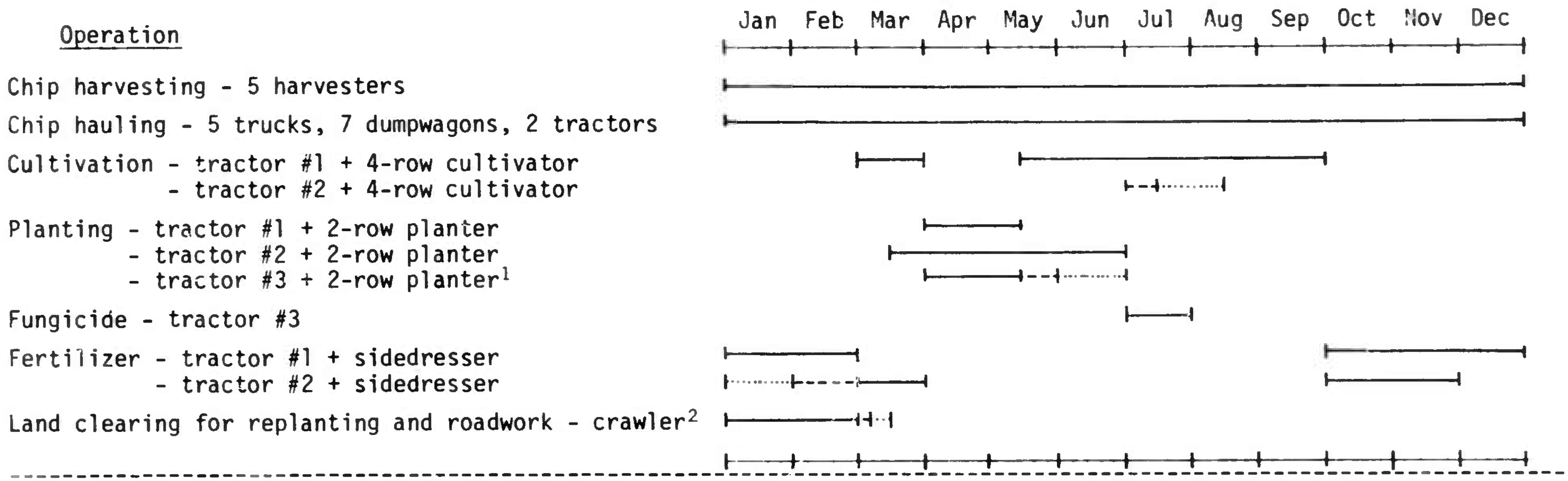
Review of the cost estimates shown in Tables F-XXIII and F-XXIV indicates that:

- while the cost of establishing and equipping plantations declines as plantation productivity increases, the fractional decline in cost is considerably less than proportional to the fractional increase in productivity;
- the greater cost of establishing and equipping plantations producing raw material for SNG than for plantations producing solid fuel is due to the higher production capacity and need for sludge trucks in the case of SNG raw material production;
- the cost of plant material harvested declines as the plantation productivity increases, but the fractional decline in cost is small compared with the fractional increase in productivity; and

TABLE F-XV

FIELD OPERATION SCHEDULE FOR 40,000 TONS PER YEAR CAPACITY

PLANTATION PRODUCTION UNIT PRODUCING SOLID FUEL FOR FORT LEONARD WOOD



Footnotes:

1. For high-yield plantation production units, this is shared with another plantation production unit.
2. Shared between four plantation production units.

Legend:

———— for high-yield plantation production units
--------- added for medium and low-yield plantation production units.
.... added for low-yield plantation production units.

TABLE F-XVI

ESTIMATED CAPITAL AND ANNUAL OPERATING COSTS FOR FIELD OPERATIONS AT A PLANTATION PRODUCTION UNIT AT FORT LEONARD WOOD PRODUCING SOLID FUEL

Machinery & Supplies	#	Capital Cost $	Maintenance Repair $/Year	Fuel Consumption Gallons/Year Gasoline	Fuel Consumption Gallons/Year Diesel	Fuel Cost $/Year	Supplies $/Year	Equipment Replacement $/Year	Payroll[1] $/Year
Harvesters	5	250,000	40,000	-	24,180	7,260	-	50,000	54,600
Chip trucks	5	83,500	3,700	22,980	-	11,040	-	15,850	45,000
Dumpwagons	7	35,000	3,500	-	-	-	-	4,375	-
Tractors	2	24,000	2,000	-	6,480	1,944	-	4,000	15,600
Tractors L[2]	3	36,000	3,000	-	7,020	2,106	-	6,000	19,500
M[3]	3	36,000	3,000	-	6,210	1,863	-	6,000	19,500
H[4]	2.5	30,000	2,500	-	5,670	1,701	-	5,000	17,550
4-row cultivator	2	4,000	900	-	-	-	-	800	-
2-row planter L	3	3,300	300	-	-	-	-	219	8,640
M	3	3,300	300	-	-	-	-	219	7,560
H	2.5	2,750	250	-	-	-	-	183	7,020
Sprayer	1	2,600	400	-	-	-	-	520	-
Crawler L	0.25	8,250	1,500	-	499	150	-	1,375	2,070
M	0.25	8,250	1,500	-	461	138	-	1,375	2,070
H	0.25	8,250	1,500	-	422	127	-	1,375	2,070
Lime[5] L	-	-	-	-	-	-	14,280	-	-
M	-	-	-	-	-	-	13,200	-	-
H	-	-	-	-	-	-	11,880	-	-
Fertilizer	-	-	-	-	-	-	89,250	-	-
Fungicide[6] L	-	-	-	-	-	-	7,410	-	-
M	-	-	-	-	-	-	6,600	-	-
H	-	-	-	-	-	-	5,940	-	-
Sidedresser 2-row	2	1,000	200	-	-	-	-	200	-
Small tools & general supplies	-	-	-	-	-	-	5,000	-	-

TABLE F-XVI (continued)

ESTIMATED CAPITAL AND ANNUAL OPERATING COSTS FOR FIELD OPERATIONS AT A PLANTATION PRODUCTION UNIT AT FORT LEONARD WOOD PRODUCING SOLID FUEL

Machinery & Supplies		#	Capital Cost $	Maintenance Repair $/Year	Fuel Consumption Gallons/Year Gasoline	Fuel Consumption Gallons/Year Diesel	Fuel Cost $/Year	Supplies $/Year	Equipment Replacement $/Year	Payroll[1] $/Year
Totals	L	-	447,650	55,500	22,980	38,170	22,500	116,480	83,339	145,410
	M	-	447,650	55,500	22,980	37,331	22,245	114,050	83,339	144,330
	H	-	441,100	54,950	22,980	36,752	22,072	112,070	82,303	141,840
Per ton Harvested	L	-	-	$1.39	0.57[7]	0.95[7]	$0.56	$2.91	$2.08	$3.64
	M	-	-	1.39	0.57[7]	0.93[7]	0.56	2.85	2.08	3.61
	H	-	-	1.37	0.57[7]	0.92[7]	0.55	2.80	2.06	3.55

Footnotes:

1. Including fringe benefits
2. L = low-yield plantation
3. M = medium-yield plantation
4. H = high-yield plantation
5. One half ton per acre at $10 per ton delivered and applied
6. $10 per acre
7. Gallons per ton of plant material harvested

- even after allowance for the difference in the annual capacity between the plantations producing plant material for solid fuel and for raw material for SNG, it is cheaper to produce the latter than the former--the reason is that the fertilizer required when producing solid fuel is more expensive per ton harvested than is the cost of returning spent sludge from the anaerobic digesters and spreading it on the plantation per ton of plant material harvested.

TABLE F-XVII

ESTIMATED CAPITAL AND ANNUAL OPERATING COSTS FOR CLONE PRODUCTION FOR A PLANTATION PRODUCTION UNIT AT FORT LEONARD WOOD

Machinery & Supplies	#	Capital Cost $	Maintenance Repair $/Year	Fuel Consumption Gallons/Year		Fuel Cost $/Year	Supplies $/Year	Equipment Replacement $/Year	Payroll[1] $/Year
				Gasoline	Diesel				
Pickup truck	1	5,600	270	576	-	276	-	1,120	-
Wagon	1	2,300	75	-	-	-	-	153	-
Supplies	-	-	-	-	-	-	3,000	-	-
Building L[2]	1	7,300	100	-	-	-	-	365	14,040
M[3]	1	6,500	100	-	-	-	-	325	12,420
H[4]	1	5,850	100	-	-	-	-	292	11,340
Totals L	-	15,200	445	576	-	276	3,000	1,638	14,040
M	-	14,400	445	576	-	276	3,000	1,598	12,420
H	-	13,750	445	576	-	276	3,000	1,565	11,340
Per ton L	-	-	$0.01	0.01[5]	-	$0.01	$0.08	$0.04	$0.35
harvested M	-	-	0.01	0.01[5]	-	0.01	0.08	0.04	0.31
H	-	-	0.01	0.01[5]	-	0.01	0.08	0.04	0.28

Footnotes:

1. Including fringe benefits
2. L = low-yield plantation
3. M = medium-yield plantation
4. H = high-yield plantation
5. Gallons per ton of plant material harvested

TABLE F-XVIII

ESTIMATED CAPITAL AND ANNUAL OPERATING COSTS FOR THE MOTOR POOL FOR A PLANTATION PRODUCTION UNIT AT FORT LEONARD WOOD PRODUCING RAW MATERIAL FOR SNG

Machinery & Supplies	#	Capital Cost $	Maintenance Repair $/Year	Fuel Consumption Gallons/Year		Fuel Cost $/Year	Supplies $/Year	Equipment Replacement $/Year	Payroll[1] $/Year
				Gasoline	Diesel				
Pickup truck	1/6	933	45	384	-	184	-	187	12,000
Building & euipment	1/6	20,000	500	-	-	-	-	1,000	-
Backup equipment:									
Harvester	1/2	25,000	-	-	-	-	-	5,000	-
Chip truck	1/2	8,350	-	-	-	-	-	1,585	-
Sludge truck	1/3	5,833	-	-	-	-	-	1,083	-
Tractor	1/2	6,000	-	-	-	-	-	1,000	-
Pickup truck	1/4	1,400	-	-	-	-	-	280	-
Dumpwagon	2/3	3,333	-	-	-	-	-	417	-
Totals	-	70,849	545	384	-	184	-	10,552	12,000
Per ton harvested	-	-	$0.01	0.01[2]	-	$0.01	-	$0.26	$0.30

Footnotes:

1. Including fringe benefits.
2. Gallons per ton of plant material harvested.

Preceding page blank

TABLE F-XIX

ESTIMATED CAPITAL AND OPERATING COSTS FOR THE MOTOR POOL FOR A PLANTATION PRODUCTION UNIT AT FORT LEONARD WOOD PRODUCING SOLID FUEL

Machinery & Supplies	#	Capital Cost $	Maintenance Repair $/Year	Fuel Consumption Gallons/Year Gasoline	Fuel Consumption Gallons/Year Diesel	Fuel Cost $/Year	Supplies $/Year	Equipment Replacement $/Year	Payroll[1] $/Year
Pickup truck	1/4	1,400	68	576	-	277	-	280	12,000
Building & Equipment	1/4	20,000	500	-	-	-	-	1,000	-
Backup equipment									
Harvester	1/2	25,000	-	-	-	-	-	5,000	-
Chip truck	1/2	8,350	-	-	-	-	-	1,585	-
Tractor	1/2	6,000	-	-	-	-	-	1,000	-
Pickup truck	1/4	1,400	-	-	-	-	-	280	-
Dumpwagon	3/4	3,750	-	-	-	-	-	469	-
Totals	-	65,900	568	576	-	277	-	9,614	12,000
Per ton Harvested	-	-	$.01	0.01[2]	-	$0.01	-	$0.24	$0.30

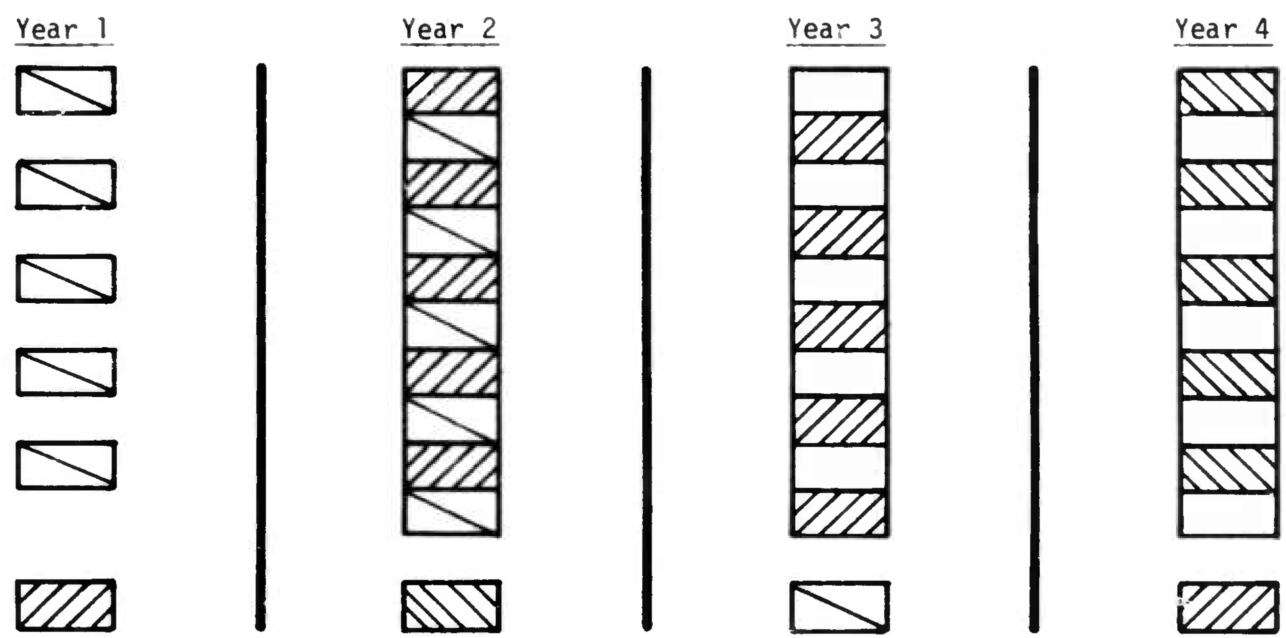
Footnotes:

1. Including fringe benefits.
2. Gallons per ton of plant material harvested.

Preceding page blank

FIGURE F-VI

SCHEDULE FOR ESTABLISHING A PLANTATION PRODUCTION UNIT TO BE OPERATED AT A 4-1-2 PLANTING DENSITY-HARVEST SCHEDULE COMBINATION



Planting area cleared during the indicated year.

Planting area harvested for the first time (when stand is one year old).

Planting area harvested for the second time.

Planting area in first year of regrowth after it was first harvested.

TABLE F-XX

OPERATIONAL PROGRAMS FOR ESTABLISHING PLANTATION PRODUCTION UNITS AT FORT LEONARD WOOD TO BE OPERATED AT A 4-1-2 PLANTING DENSITY-HARVEST SCHEDULE COMBINATION

Year	Operation	Plantation Productivity[1] Low	Medium	High
1	Acres to be cleared-6 planting areas	2,964	2,640	2,376
	Acres to be planted-1 planting area	494	440	396
	Number of clones to buy (thousands)	5,379	4,792	4,312
	Tractor-months to clear land	12.6	11.2	10.0
	Tractor-months to cultivate-5 unplanted acres	12.7	11.3	10.2
	Tractor-months to plant clones	8.0	7.0	6.3
	Tractor-months to cultivate 1 planted area	2.0	1.8	1.60
	Fertilizer per planting area - tons	2.86	2.81	2.76
	Tractor-months to fertilize-1 planting area	1.7	1.5	1.4
	Lime required per planting area - tons	247	220	198
	Number of clones needed for year 2 (thousands)	26,898	23,958	21,562
	Team-months needed to produce clones	43.3	38.6	34.7
	Plant material harvested-o.d. tons	214	209	205
	Harvester-months for harvesting	0.32	0.31	0.31
2	Acres to be cleared-5 planting areas	2,470	2,200	1,980
	Acres to be planted-5 planting areas	2,470	2,200	1,980
	Tractor-months to clear land	10.5	9.3	8.4
	Tractor-months to cultivate cleared land	10.6	9.4	8.5
	Tractor-months to plant clones	39.0	34.7	31.2
	Tractor-months to cultivate planted area	9.8	8.7	7.8
	Fertilizer for six planting areas - tons	31.9	31.75	31.5
	Lime for 5 planting areas - tons	1,235	1,100	990
	Team-months for clone production	43.3	38.6	34.7
	Plant material harvested-o.d. tons	4,642	4,601	4,538
	Harvester-months for harvesting	7.0	6.9	6.8
	Tractor-months for fertilizing	10.3	9.2	8.3
3	Acres to be planted-5 planting areas	2,470	2,200	1,980
	Tractor-months to plant clones	39	34.7	31.2
	Tractor-months to cultivate planted area	9.8	8.7	7.8
	Fertilizer for 11 planting areas - tons	46.2	45.8	45.3
	Lime for five planting areas - tons	1,235	1,100	990
	Tractor-months for fertilizing	18.9	16.8	15.1
	Plant material harvested-o.d. tons	4,642	4,601	4,538
	Harvester-months for harvesting	7.0	6.9	6.8

Footnote: 1. Assuming hybrid poplars well adapted to the Fort Leonard Wood region are to be planted. A low productivity plantation is expected to have an average annual sustained harvestable yield of 7.4 tons (oven-dry basis) per acre-year. The corresponding yields in plantations of medium and high productivity are expected to be 8.3 and 9.2 tons per acre-year,respectively.

Preceding page blank

TABLE F-XXI

OPERATING RATES AND COSTS PER MONTH FOR PLANTATION OPERATIONS DURING PLANTATION ESTABLISHMENT

Operation	Operating Rate Per Month	Cost Per Month [1]
Land clearing - crawler tractor	260 acres	$1,933
Cultivation - tractor + cultivator	700 acres	1,052
Cultivation of established plantation - tractor + cultivator	760 acres	1,052
Planting of clones	690,000 clones	2,075
Clone production	621,000 acres	2,517
Fertilizer spreading	288 acres	996
Harvester	667 o.d. tons	2,531

Footnote:

1. Fuel, equipment maintenance, supplies, payroll and fringe benefits, and annual equipment replacement cost.

Preceding page blank

TABLE F-XXII

ESTIMATED COSTS OF ESTABLISHING PLANTATION PRODUCTION UNITS OPERATED ON A 4-1-2 PLANTING DENSITY-HARVEST SCHEDULE COMBINATION AT FORT LEONARD WOOD*

		Plantation Productivity**		
Year	Operation	Low	Medium	High
1	Land clearing	$ 22,036	$ 19,627	$ 17,665
	Land preparation	13,363	11,903	10,712
	Clones purchased	53,797	47,916	43,124
	Clone planting	16,178	14,409	12,969
	Cultivating planted area	2,051	1,827	1,644
	Fertilizer	486	478	469
	Fertilizer application	1,708	1,522	1,369
	Lime @$10/ton delivered & spread	2,470	2,200	1,980
	Clone production	109,022	97,105	87,395
	Supervision-payroll & fringe benefits	9,300	9,300	9,300
	Supervision-other costs	1,416	1,416	1,416
	Motor pool payroll	2,000	2,000	2,000
	Motor pool-other costs	729	729	729
	Totals - year 1	$234,556	$210,432	$190,772
2	Land clearing	$ 18,363	$ 16,356	$ 14,720
	Land preparation	11,136	9,919	8,927
	Planting	80,890	72,048	64,843
	Cultivating planted area	10,257	9,136	8,222
	Fertilizer	5,423	5,397	5,355
	Fertilizer application	10,250	9,130	8,217
	Lime @$10/ton delivered & spread	12,350	11,000	9,900
	Clone production	109,022	97,105	87,395
	Harvesting	17,614	17,459	17,220
	Supervision-payroll & fringe benefits	11,900	11,900	11,900
	Supervision-other costs	3,539	3,539	3,539
	Motor pool-payroll & fringe benefits	4,000	4,000	4,000
	Motor pool-other costs	1,458	1,458	1,458
	Totals - year 2	$296,202	$268,447	$245,696
3	Planting	$ 80,890	$ 72,048	$ 64,843
	Cultivating planted & harvested area	14,360	12,790	11,511
	Fertilizer	7,854	7,786	7,701
	Fertilizer application	18,793	16,738	15,064
	Lime at $10/ton delivered & spread	12,350	11,000	9,900

TABLE F-XXII
(continued)

ESTIMATED COSTS OF ESTABLISHING PLANTATION PRODUCTION UNITS OPERATED ON A 4-1-2 PLANTING DENSITY-HARVEST SCHEDULE COMBINATION AT FORT LEONARD WOOD*

Year	Operation	Plantation Productivity** Low	Medium	High
3	Harvesting	$ 17,614	$ 17,459	$ 17,220
	Supervision-payroll & fringe benefits	14,500	14,500	14,500
	Supervision-other costs	5,663	5,663	5,663
	Motor pool-payroll & fringe benefits	6,000	6,000	6,000
	Motor pool-other costs	2,187	2,187	2,187
	Total - year 3	$180,211	$166,171	$154,589
	Grand total - 3 years	$710,969	$645,050	$591,057

Footnotes:

* The costs shown in this table do not include the capital cost of the field machinery and facilities required for the plantation production units. The costs shown assume that the plantation will consist of six plantation production units.

** Assuming hybrid poplars well adapted to the Fort Leonard Wood region are to be planted. A low productivity plantation is expected to have an average annual harvestable yield of 7.4 tons (oven-dry basis) per acre. The comparable yields for medium and high productivity plantations are expected to be 8.3 and 9.2 tons per acre-year, respectively.

TABLE F-XXIII

ESTIMATED COSTS OF ESTABLISHING, EQUIPPING AND OPERATING PLANTATIONS ON A 4-1-2 PLANTING DENSITY-HARVEST SCHEDULE COMBINATION AT FORT LEONARD WOOD

Plantation capacity: 240,000 tons (oven-dry basis) per year for SNG production.

Cost Factor	Plantation Productivity		
	Low	Medium	High
Plantation Establishment:			
• First year	$1,407,000	$1,263,000	$1,145,000
• Second year	1,777,000	1,611,000	1,474,000
• Third year	1,081,000	997,000	928,000
Subtotal:	$4,265,000	$3,871,000	$3,547,000
Equipment and Facilities:	3,639,000	3,634,000	3,591,000
Total Plantation Cost:	$7,904,000	$7,505,000	$7,138,000
Annual Operating Costs:			
• Payroll and fringe benefits	$1,308,000	$1,292,000	$1,271,000
• Other operating costs	752,000	737,000	721,000
• Equipment replacement cost	654,000	654,000	648,000
• Plantation maintenance cost	128,000	116,000	106,000
Total Annual Operating Costs	$2,842,000	$2,799,000	$2,746,000
Operating cost per ton (oven-dry basis)	$11.84	$11.66	$11.44

Preceding page blank

TABLE F-XXIV

ESTIMATED COSTS OF ESTABLISHING, EQUIPPING AND OPERATING PLANTATIONS ON A 4-1-2 PLANTING DENSITY-HARVEST SCHEDULE COMBINATION AT FORT LEONARD WOOD

Plantation capacity: 180,000 tons (oven-dry basis) per year for solid fuel.

Cost Factor	Plantation Productivity		
	Low	Medium	High
Plantation Establishment:			
• First year	$1,055,000	$ 947,000	$ 858,000
• Second year	1,333,000	1,208,000	1,106,000
• Third year	810,000	748,000	696,000
Subtotal:	$3,199,000	$2,903,000	$2,660,000
Equipment and Facilities:	$2,402,000	$2,398,000	$2,366,000
Total Plantation Cost:	$5,601,000	$5,301,000	$5,026,000
Annual Operating Costs:			
• Payroll and fringe benefits	$ 859,000	$ 846,000	$ 830,000
• Other operating costs	925,000	913,000	901,000
• Equipment replacement cost	430,000	430,000	425,000
• Plantation maintenance cost	96,000	87,000	80,000
Total Annual Operating Costs	$2,310,000	$2,276,000	$2,236,000
Operating cost per ton (oven-dry basis)	$12.83	$12.64	$12.42

Preceding page blank

VI. SENSITIVITY ANALYSIS

VI.A. Introduction. Section V is devoted to descriptions of the operations and costs of Energy Plantations, suitable for Fort Leonard Wood, producing either raw material for SNG or solid fuel. Three levels of productivity representative of the average annual yields predicted from the yield maximization calculations for the area of the fort (see Table F-VII) have been considered. In each case considered, it is assumed that the optimum planting density and harvest schedules (that is,4-1-2) are used in the plantations.

However, as has been noted in Appendix C, section VIII, in many cases the second best planting density-harvest schedule combination leads to average annual yields which are less than five percent smaller than those expected from the optimum combination. For example, in the case of poplar NE-388, changing the planting density-harvest schedule combination from the optimum 4-1-2 combination to a 6-1-2 combination results in a loss of average annual yield of only about three percent. The economic implications of such a small reduction in planting density could be significant.

The purpose of the present section is to examine the impact of variation in plantation operational parameters on the economics of plant-material production. The analysis is based on production of plant material for SNG raw material, but similar conclusions would be reached if the analysis were based on plant material produced for solid fuel.

VI.B. Influence of Plantation Parameters. Table F-XXV is a summary of the results of the sensitivity analysis. The base case (#1 in the table) is the medium-yield case from section V for a plantation producing 240,000

tons (oven-dry basis) of plant material per year for use as raw material for SNG.

The effects of varying factors under plantation management control on the cost of plant material produced (see Table F-XXV) are plotted in Figure F-VII. The values on the abscissa are the value of the factor varied relative to its value in the base case. The values on the left-hand ordinate are costs of plant material relative to the corresponding cost in the base case. The values on the right-hand ordinate are costs of plant material. Figure F-VIII is similar to Figure F-VII, except that the ordinates are the plantation areas required relative to the plantation area in the base case. Figure F-IX is also similar to Figure F-VII, except that the ordinates are the cost of establishing and equipping the plantation relative to that cost for the base case.

<u>VI.B.1. Plant Species or Yield Per Acre-Year</u>. It is well known that closely related plant species will produce significantly different yields at a given planting site. This point is well illustrated by the yields from three different hybrid poplars grown at the same site in central Pennsylvania[6]. Some species are better adapted to the site--a factor reflected for Fort Leonard Wood in the species recommendations summarized in Table F-V. It is apparent in Figure F-VII that choosing a species better adapted to the site tends to reduce the cost of plant material produced. Choosing species well adapted to the site also reduces the plantation area required (see Figure F-VIII) and the cost of establishing and equipping the plantation (see Figure F-IX). Effective as careful species selection is on the performance of the plantation, there is a limit on the range of this effect. It is doubtful, for instance, if any species can be found for the Fort Leonard Wood area which will produce a yield much over about nine tons (oven-dry basis) per acre-year because of the climate, rainfall pattern and soil character in the locality of the fort.

TABLE F-XXV

INFLUENCE OF PLANTING DENSITY AND HARVEST SCHEDULE ON PLANT MATERIAL-ANNUAL YIELDS, REQUIRED PLANTATION AREA, AND PLANTATION CAPITAL AND OPERATING COSTS

Basis: A medium-yield plantation at Fort Leonard Wood producing 240,000 tons (oven-dry basis) of plant material per year for SNG production

#	Factor Varied	Planting Area Per Plant Square Feet	Harvest Schedule	Total Harvests Per Planting	Average Annual Yield Tons(o.d.)Per Acre	Plantation Area Acres	Plantation Cost[1]	Plant-Material Cost $ Per Ton (o.d.)
1	Base case	4	1 - 2	6	8.3	29,000	$7,505,000	$11.66
2	Stand age	4	2 - 2	6	7.6	31,600	8,384,000	11.50
3	at first harvest-years	4	3 - 2	6	7.0	34,300	9,856,000	11.87
4	Interval between	4	1 - 3	6	7.5	32,400	7,024,000	11.04
5	harvests - years	4	1 - 4	6	6.6	36,300	8,282,000	10.98
6	Planting density-	8	1 - 2		7.7	31,200	6,592,000	10.86
7	sq. ft. per plant	10	1 - 2	6	7.5	32,200	6,262,000	10.87
8	Number of har-	4	1 - 2	8	8.5	28,400	7,286,000	11.14
9	vests from the stand	4	1 - 2	11	8.6	27,800	7,116,000	10.83

Footnote:

1. Cost of establishing and equipping the plantation.

VI.B.2. Stand Age at First Harvest. Increasing the age of the stand at its first harvest from the optimum 4-1-2 program to 4-2-2 or 4-3-2 reduces the annual average yields per acre by eight and sixteen percent, respectively. However, the cost of plant material is hardly affected--it declines slightly and then rises in going from 4-1-2 to 4-2-2 and then to 4-3-2 (Figure F-VII). The effects on plantation area and cost of establishing and equipping the plantation are far more drastic. The former increase nine and eighteen percent, and the latter twelve and thirty-one percent in going from 4-1-2 to 4-2-2 and 4-3-2, respectively.

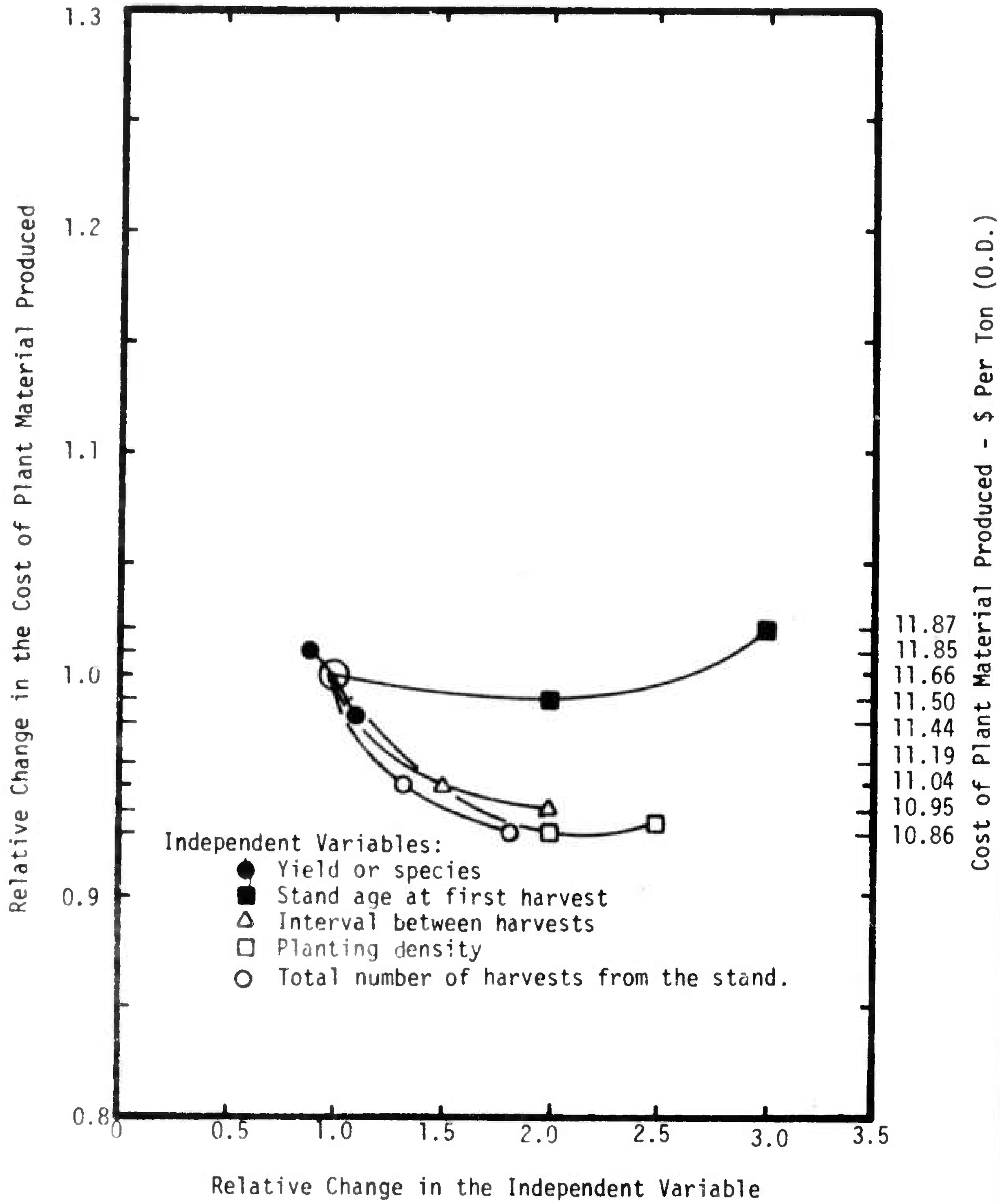
VI.B.3. Interval Between Harvests. Lengthening the interval between harvests, that is replacing the optimum 4-1-2 combination by 4-1-3 or 4-1-4, reduces average annual yields by 10 and 20 percent, respectively. The changes in the interval between harvests results in larger changes in average yields than is the case for changes in the age of the stand at first harvest, because the major part of the annual yield in a plantation is harvested from areas in the plantation in their second or subsequent growth periods.

Increasing the interval between harvests from two to three years reduces plant material cost by about five percent (Figure F-VII), increases the plantation area by about twelve percent (Figure F-VIII) and decreases the cost of establishing and equipping the plantation by about six percent (Figure F-IX). Increasing the interval between harvests to four years lowers the cost of plant material by about six percent of the value for the optimum cycle, but increases the required plantation area by about twenty-five percent, and the cost of establishing and equipping the plantation by ten percent.

FIGURE F-VII

EFFECT OF FACTORS UNDER PLANTATION MANAGEMENT CONTROL ON THE COST OF PLANT MATERIAL PRODUCED

(Based on estimates shown in Table F-XXV)



VI.B.4. Planting Density. Decreasing the planting density from one plant every four square feet to one every eight or ten, decreases the average annual yield per acre by seven and ten percent, respectively. The cost of plant material declines by about seven percent for each of the lower planting densities. However, the plantation area required increases eight and eleven percent, and the cost of establishing and equipping the plantation declines twelve and seventeen percent at the two lower planting densities, respectively.

VI.B.5. Total Number of Harvests from a Stand. Increasing the total harvests from six to eight or eleven is estimated to cause a small increase in average annual yield per acre and a small decrease in the required plantation area. The costs of plant material and of establishing and equipping the plantation decline a few percent. However, because there are no data available for confirming the effect of increasing the total number of harvests beyond six on the average annual yield, there is no way for being sure that the effects on plant-material cost, plantation area or the cost of establishing and equipping the plantation are realistic.

FIGURE F-VIII

EFFECT OF FACTORS UNDER PLANTATION MANAGEMENT CONTROL ON THE REQUIRED PLANTATION AREA

(Based on estimates shown in Table F-XXV)

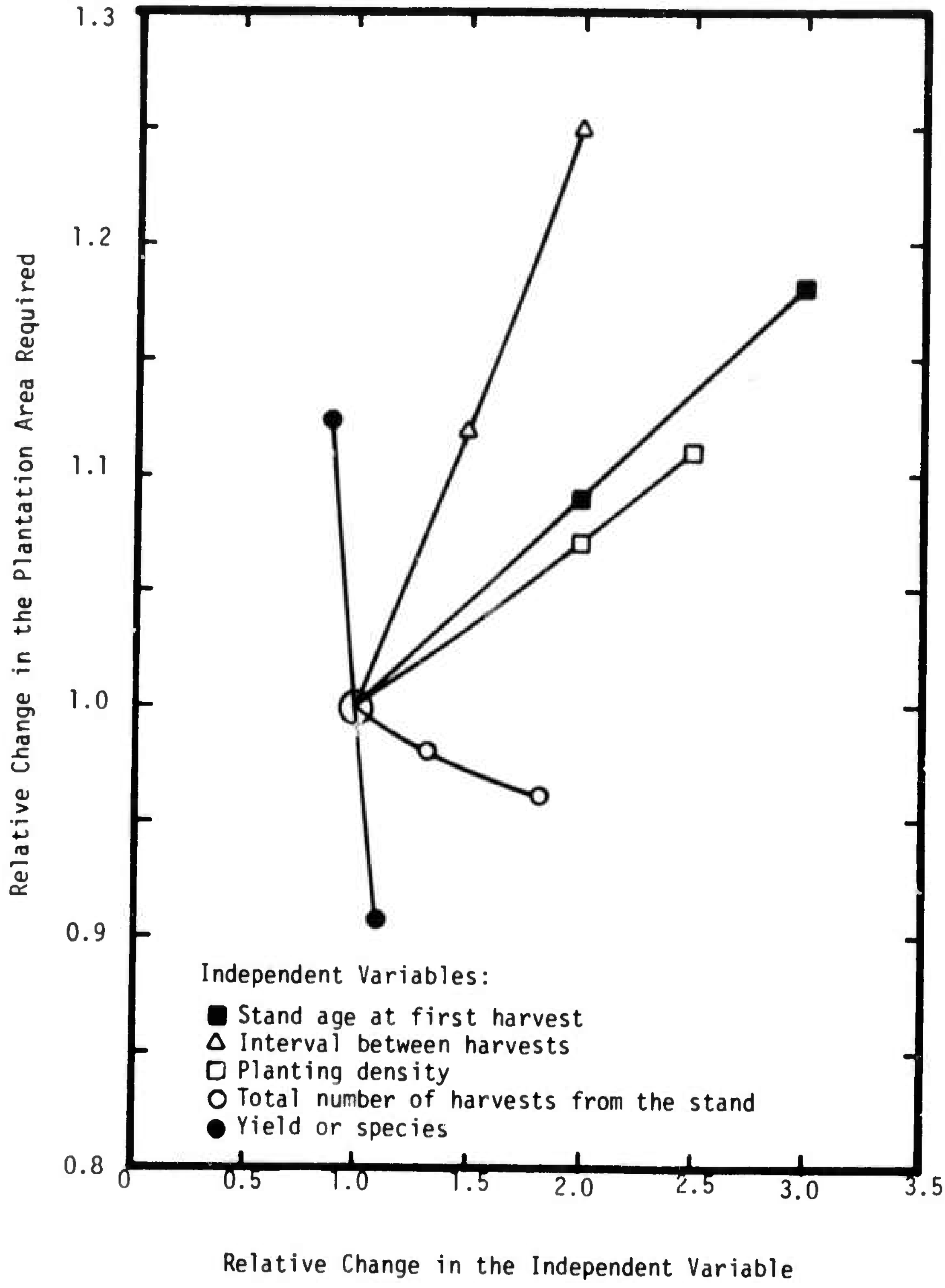
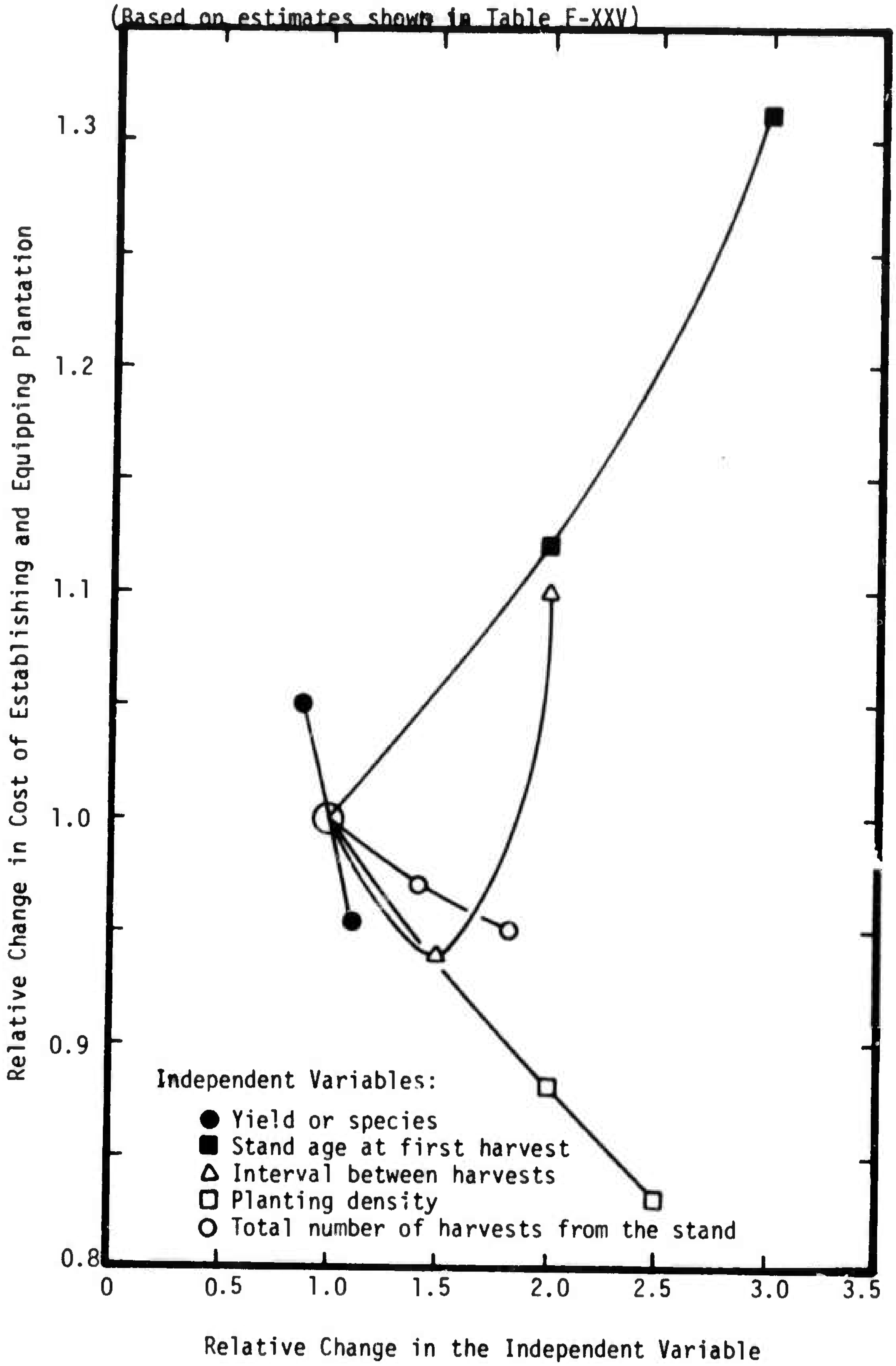


FIGURE F-IX

EFFECT OF FACTORS UNDER PLANTATION MANAGEMENT CONTROL

ON THE COST OF ESTABLISHING AND EQUIPPING THE PLANTATION

(Based on estimates shown in Table F-XXV)



Preceding page blank

VII. CONCLUSIONS

The recommended operating schedules for plantations at or in the vicinity of Fort Leonard Wood, and estimated associated costs are summarized in Table F-XXVI. On the first line in the table are estimates at the probable maximum average annual sustained yield per acre for plantations serving the fort. They reflect, therefore, the probable minimum plantation areas estimated to be required for meeting the energy needs at the fort with SNG or with solid fuel. The estimates on the second line are similar to those on the first, except that they are based on the upper limit of the estimated range in the average annual sustained yield per acre expected for the Fort Leonard Wood area. They are therefore rather unlikely to be attained. Moreover, from a practical point of view, it could not be known whether yields approaching the upper limit can be attained until after the plantation has been in operation for some time. Therefore, no saving is likely to be possible in the cost of establishing and equipping the plantation because it would be prudent to establish it on the assumption that the annual yield is much more likely to be nearer the median than the high yield. However, if experience with the plantation indicates that yields are on the high side, the plantation area can be reduced and the benefit of the lower plant-matter production cost can be taken.

It has been noted that the plantation having the minimum area capable of meeting the fuel requirements at Fort Leonard Wood is not the plantation which produces plant material at the lowest cost. The lowest-cost plantation requires a larger area. This point is reflected in the third and fourth lines of the table. Line three is for medium-yield plantations which are estimated to produce the lowest-cost plant material, and

Preceding page blank

line four is for plantations whose yields are at the upper limit of the estimated yields for the locality of the fort. Generally speaking, these lowest-cost plantations require about fifteen percent more land than the highest-yield plantations. But their initial establishment and equipment costs are estimated to be lower by about fifteen percent, and their estimated costs of plant material are about ten percent lower than for plantations having the minimum area.

TABLE F-XXVI

SUMMARY OF ESTIMATES FOR ENERGY PLANTATIONS AT FORT LEONARD WOOD

Basis: 240,000 tons (oven-dry basis) required per year for SNG, and 180,000 tons for solid fuel

		For Raw Material for SNG			For Solid Fuel		
	Planting Density and Harvest Schedule	Plant Material $ Per O.D. Ton	Plantation Area Acres	Plantation Cost[1] $	Plant Material $ Per O.D. Ton	Plantation Area Acres	Plantation Cost[1] $
Plantations having minimum area:							
- medium yield	4 - 1 - 2	$11.66	29,000	$7,505,000	$12.64	21,800	$5,301,000
- high yield	4 - 1 - 2	$11.44	26,200	7,138,000	$12.42	19,700	5,026,000
Plantations having lowest production cost:							
- medium yield	8 - 1 - 3	$10.50	33,400	$6,500,000	$11.50	25,000	$4,600,000
- high yield	8 - 1 - 3	$10.50	30,000	6,200,000	$11.40	22,500	4,300,000

Footnote :

1. Cost of establishing and equipping the plantation.

VIII. REFERENCE LIST

1. Climatic Atlas of the United States, Environmental Science Services Administration, Environmental Data Service, U. S. Department of Commerce, June 1968.

2. Climatology of the United States, No. 81 (by state), National Climatic Center, U. S. Department of Commerce, Asheville, N. C., August 1973.

3. United States Department of Agriculture, Soil Conservation Service and Forest Service, and Missouri Agricultural Experiment Station Soil Survey: Dent County, Missouri, March 1971.

4. Monthly Normals of Temperature, Precipitation and Heating and Cooling Degree-Days - 1941 to 1970, National Climatic Center, U. S. Department of Commerce, Asheville, N.C., August 1973.

5. Climatological Data - Missouri Volumes 74 to 77, Environmental Data Service, U. S. Department of Commerce, Asheville, N.C.

6. Todd W. Bowersox - Private Communication.

7. Klaus Steinbeck, Tyrus R. Sockwell and Roger F. Presnell - Private Communication, August 12, 1974, unpublished results.

8. Klaus Steinbeck and Jack T. May - Forest Biomass Studies, Misc. Publ. #132, Life Sciences and Agriculture Experiment Station, University of Maine, Orono, 1971, p. 153-162.

9. Wayne A. Geyer - Private Communication, July 1974.

10. Wayne A. Geyer - Private Communication, Kansas State University - soil survey at the Milford site.

11. R. M. Krinard - Tree Planters' Notes, 22, No. 4, 1971.

12. Norris E. Austin - Land Reserve Regions and Major Land Resource Areas of the United States, Agriculture Handbook 296, Soil Conservation Service, U. S. Department of Agriculture, December 1965.

13. Opekasit, Inc., Operational Data for Fort Leonard Wood, November 1974.

14. Russell M. Burns and Edwin A. Hebb, Site Preparation and Reforestation of Droughty, Acid Sands, Agriculture Handbook, No. 426, Forest Service, USDA, October 1972.

APPENDIX G

ENERGY PLANTATION FOR FORT BENNING

TABLE OF CONTENTS

TABLE OF CONTENTS

(continued)

I. INTRODUCTION AND SUMMARY

Plantations having minimum area and minimum plant-material production cost for supplying Fort Benning with solid fuel and raw material for SNG are defined in this appendix. The factors considered are similar to those considered for Fort Leonard Wood in Appendix F, and frequent reference is made to that appendix.

It is concluded that deciduous tree species will be most satisfactory for plantations at Fort Benning. Careful attention has been given to the possibility of using warm-season grasses, but the growing season is not quite long enough to make them a satisfactory choice.

The climate, rainfall distribution and soil character at Fort Benning lead to the conclusion that the growth potential at and in the vicinity of the fort for selected deciduous species is good, in fact probably in the highest range likely to be found at any of the major troop training centers in localities suitable for Energy Plantations. It is expected that average annual sustained yields will be between about 7.8 and 9.8 tons (oven-dry basis) per acre. The most probable yield is expected to be about 8.8 tons per acre-year. These yields are higher than those expected for Fort Leonard Wood.

The preferred species for plantations at Fort Benning are varieties of hybrid poplar, eastern cottonwood and sycamore. Other species are also identified which are classified as good prospects, but for various reasons they are not quite as satisfactory as the preferred species.

If solid fuel is to be grown at Fort Benning, required annual production for meeting the fuel requirement in the fixed facilities at the base will be about 220,000 tons (oven-dry basis). This fuel is expected to cost between

$12.30 and $12.70 per ton, or the equivalent of between about $1.00 and $1.10 per million Btu, based on the lower heating value of the fuel, if it is grown under conditions which minimize the plantation area required. If the plantation is operated for the Army by a contractor, these costs would be 30 to 50 percent higher because certain capital charges neglected in this analysis would have to be included. The minimum area required is between about 25,000 and 31,000 acres, the actual area depending on the average annual sustained yield per acre in the plantation.

If raw material for SNG is to be grown, about 280,000 tons (oven-dry basis) per year will be required. The estimated cost of this plant material will be between about $11.10 and $11.50 per ton, and the plantation area required will be between 29,000 and 36,000 acres, if plantation operations are chosen which minimize the necessary plantation area.

Sensitivity analysis indicates that if plantation operations are chosen to minimize the cost of the plant material grown, the plantation areas required will be about ten percent larger than the minimum areas required for meeting the full needs at Fort Benning with either solid fuel or SNG. Under these conditions, however, the cost of plant material will be about ninety cents less per ton than is expected from plantations in which operations are chosen to minimize the land required.

II. COMPARISON BETWEEN THE FORT BENNING AREA AND AREAS FOR WHICH YIELDS OF DECIDUOUS-TREE PLANTATIONS HAVE BEEN ESTIMATED

II.A. General Geographic and Climatic Characteristics. The main geographic and climatic characteristics of the sites considered are shown in Table G-I. The Athens, Georgia, and Stoneville, Mississippi, sites are the most nearly similar to the Fort Benning area. The Kansas and Pennsylvania sites have less favorable climate, having shorter frost-free periods, cooler normal temperatures and less rainfall, but they have fewer days with temperatures exceeding 90° Fahrenheit.

Limited deciduous-species growth data are also available from sites around Bainbridge in south Georgia. However, the data from these sites are too limited to allow inclusion of the Bainbridge sites in the overall comparison of growth potential between sites.

II.B. Comparison of the Sites of Interest on the Basis of Temperature Distribution, Insolation and Rate of Photosynthesis. The procedure described in Table C-XVI in Appendix C has been applied to the Fort Benning locality. The results are given in Table G-II along with the results previously derived for other locations of interest (see Table F-II, Appendix F).

The "high" values for y_n/y_0 are estimates of the fractional increases in plant material during a growing season by plants which are two years old or younger, that is in the period when all leaves contribute to photosynthesis. The "low" values apply to plants whose plant material above ground is over two years old, by which age only about twenty percent of the leaf area contributes to photosynthesis.

The ratios of the values of y_n/y_o between Fort Benning and each of the other localities indicate that the growth potential at Fort Benning is likely to be considerably higher than at the Kansas or Pennsylvania sites before the plant material above ground is about two years old, but that after that time the fractional increase in plant material during growing seasons is likely to be about the same at all three sites. The ratios between Fort Benning and the Athens and Stoneville sites suggest that growth potentials at these three sites will be about the same irrespective of the age of the plant material above ground.

<u>II.C. Comparison of the Sites of Interest on the Basis of Soil Quality and Moisture Availability During the Growing Season</u>. As discussed in Appendix F, rainfall,and particularly its distribution during the growing season, are important factors influencing the rate of plant growth.

The precipitation normals for the locations considered in this appendix as well as the average number of days with precipitation greater than 0.01 inches are shown in Table G-III. Annual precipitation is essentially the same at Fort Benning, Athens, Georgia, and the Mississippi site, and considerably higher than at the Pennsylvania and Kansas sites.

Normally expected precipitation is greater during the growing season at Fort Benning (four inches or more every month in the year except September, October and November) than it is at either Athens (less than four inches per month in June and in August, September, October and November) or Stoneville where it is less than four inches per month in the five-month period beginning with June. In most months during the year, precipitation at Fort Benning is about equal to or greater than that at the Kansas and Pennsylvania sites.

TABLE G-I

GENERAL GEOGRAPHIC AND CLIMATIC CHARACTERISTICS OF FORT BENNING AND OTHER LOCALITIES

Factors	Fort Benning, (Columbus, Georgia)	Manhattan, Kansas	State College, Pennsylvania	Athens, Georgia	Stoneville, Mississippi
Latitude	N 32° 31'	N 39° 12'	N 40° 48'	N 33° 55'	N 33° 25'
Elevation - feet	385	1,065	1,175	685	127
Annual Normal Temperature - °F	64.3	55.1	49.7	62.0	63.7
Annual Normal Precipitation - In.	50.94	33.52	36.77	49.35	50.37
Annual Normal Heating Degree-Days	2,378	5,085	6,132	2,821	2,630
Annual Normal Cooling Degree-Days	2,143	1,501	583	1,748	2,189
Frost-Free Period - Days	260	183	158	244	252
Mean Number of Days With Temperature over 90°F	80	53	24	57	68

Sources:

References 1 and 2.

The distribution of precipitation during the growing season, as indicated by the normally expected number of days in each month on which measurable precipitation occurs (more than 0.01 inches), at Fort Benning is approximately on a par with that at Athens and State College, and somewhat more regular than at either Manhattan or Stoneville.

The two main soil types at Fort Benning considered for the plantation are sandy loam uplands and Ochlocknee bottomlands. Both of these soils are porous enough to absorb sufficient moisture to maintain the rate of plant growth at a relatively steady level between rainfalls during the growing season. This conclusion is supported by the fact that site indices at Fort Benning are medium to high for slash and loblolly pine and for eastern cottonwood and sycamore.

To summarize, it is expected that the soil moisture availability and soil types at Fort Benning are more favorable for deciduous species than is the case for Fort Leonard Wood. In particular, at Fort Benning there is likely to be less interference with the growth rate during dry spells than at Fort Leonard Wood.

TABLE G-II

GROWTH POTENTIAL ESTIMATES FROM CLIMATIC DATA FOR LOCALITIES SHOWN IN TABLE G-I

Location	y_n/y_o Low[1]	y_n/y_o High[2]	(y_n/y_o)F.B./(y_n/y_o)Other[3] Low[1]	(y_n/y_o)F.B./(y_n/y_o)Other[3] High[2]
Fort Benning, Georgia	1.90	15.51	-	-
Manhattan, Kansas	1.78	10.60	1.07	1.46
State College, Pennsylvania	1.85	12.75	1.03	1.22
Athens, Georgia	1.87	14.57	1.02	1.06
Stoneville, Mississippi	1.91	16.36	0.99	0.95

Footnotes:

1. For plants whose plant material above ground is over two years old.
2. For plants whose plant material above ground is two years old or younger.
3. Ratios of y_n/y_o for Fort Benning to those of other locations.

TABLE G-III

NORMAL PRECIPITATION AND DAYS WITH MEASURABLE PRECIPITATION AT FORT BENNING AND OTHER LOCALITIES SHOWN IN TABLE G-I

	Fort Benning		Athens Georgia		Manhattan, Kansas		Stoneville, Mississippi		State College, Pennsylvania	
	Precip. Inches	Days	Precip. Inches	Days	Precip. Inches	Days	Precip. Inches	Days	Precip. Inches	Days
Jan.	4.34	10	4.66	12	0.86	5	4.63	10	2.35	12
Feb.	4.40	10	4.56	11	0.92	6	5.21	10	2.10	9
Mar.	6.03	11	5.80	13	1.85	7	5.63	11	3.43	12
Apr.	4.50	9	4.47	11	3.00	9	5.09	9	3.33	12
May	4.05	9	4.03	10	4.35	11	4.58	9	4.0	13
Jun.	4.12	10	3.77	12	5.84	11	3.67	9	3.25	11
Jul.	5.75	13	4.92	13	4.38	8	3.78	9	3.55	10
Aug.	4.22	11	3.28	11	3.60	7	2.78	9	3.40	10
Sep.	3.67	9	3.31	9	3.96	7	3.08	7	2.60	8
Oct.	1.97	7	2.83	7	2.72	6	2.51	6	2.80	8
Nov.	2.96	7	3.41	9	0.98	4	4.42	8	3.30	9
Dec.	4.93	10	4.31	10	1.06	5	4.99	10	2.60	10
Total Inches	50.94		49.35		33.52		50.37		36.77	

Sources: References 1 and 3.

Preceding page blank

III. CHOICE OF SPECIES FOR ENERGY PLANTATIONS AT FORT BENNING

Two classes of perennial plants may be considered for plantations in the Fort Benning area. They are certain deciduous tree species well adapted to the soils and climate in the area and selected perennial warm-season grasses.

Among the warm-season grasses which merit consideration are bermudagrass and some of its hybrids. These grasses have been shown to yield eight or more tons (oven-dry basis) per acre-year when grown for forage in central and southern Georgia. These grasses offer the same desirable characteristics for plantation culture as the deciduous species. Thus, they grow rapidly when local soil and climate conditions suit them, support repeated harvesting from a stand and are readily reproduced by vegetative means.

The growing season for warm-season grasses, however, is shorter than that for deciduous species, because the grasses grow at a perceptible rate only when the ambient temperature is over 55° Fahrenheit, whereas deciduous species begin growing noticeably at a temperature about ten degrees lower. Consequently, the growing season for warm-season grasses at Fort Benning begins in April and ends in October, whereas for deciduous species it is from late February to well into November. Moreover, in order to achieve high yields from the warm-season grasses, they must be harvested regularly at three to four-week intervals in the growing season. They cannot be harvested in response to the demand for plant material throughout the year as the deciduous species can. This means that at the end of the growing season for warm-season grasses, an inventory of harvested plant material equal to about six months' supply would have to be in storage. At Fort Benning, this inventory will be at least one hundred thousand tons, which must be

protected from deterioration and spontaneous fire and be prevented from generating noxious odors. Moreover, most of the plantation machinery and work force will be idle five or more months a year.

This seasonal schedule will make it difficult to staff the plantation and will increase its capital cost.

It is concluded that the growing season for warm-season grasses is too short to make them a suitable species for plantations at Fort Benning.

Deciduous species recommended for plantations at Fort Benning are shown in Table G-IV. The species selection is based on data collected and observations made during a visit to the Fort Benning area and recommendations of persons who are familiar with growing conditions and species suitability in the area (see Appendix H). A number of eastern cottonwood varieties specially suitable to the Fort Benning area have been identified by the Southern Forest Experiment Station of the U.S. Department of Agriculture[4]. Recommended hybrid poplar varieties are listed in Table G-V.

TABLE G-IV

DECIDUOUS SPECIES RECOMMENDED FOR ENERGY PLANTATIONS AT FORT BENNING

Suitability Ranking	Species	Comments
For Bottomland Ocklocknee Soils:		
Highly recommended	Hybrid poplars	See Table G-V
	Eastern cottonwood	Varieties recommended in reference 4.
	Sycamore	Where flooding is infrequent and of short duration.
Good prospects	Red maple	
	European black alder	Suitable for acid soils, fixes nitrogen, many varieties available.
	Green ash	Probably as suitable as sycamore.
	Sweetgum	Soil suitability could be a problem.
For Upland Sandy Loams:		
Highly recommended	Hybrid poplars	Varieties from Table G-V.
	Eastern cottonwood	See reference 4.
	Sycamore	
Good prospects	Missouri cottonwood	
	European black alder	
	Green ash	
	Sweetgum	

TABLE G-V

CANDIDATE VARIETIES OF HYBRID POPLAR FOR ENERGY PLANTATIONS AT FORT BENNING

1. *P. deltoides* Bartr x *deltoides* Bartr--Stoneville clones among others
2. *P. deltoides* x *trichocarpa*--Clones NE-200 to -220 and -345 to -350
3. *P. deltoides* x cv. Caudina--Clones NE-351 to -367
4. *P. maximowiczii* x *trichocarpa*--Clones NE-41, -42, -388
5. *P. maximowiczii* x cv. Berolinensis--Clones NE-43 to -50
6. P. cv. Angulata x *deltoides*--Clones NE-244 to -247
7. P. cv. Angulata x *trichocarpa*--Clones NE-248 to -258 and NE-372 to -374

IV. PREDICTED YIELDS AND SUGGESTED HARVEST SCHEDULES

Optimization calculations for the principal species of interest in the Fort Benning area have been described in section VIII of Appendix C. These calculations were made on the basis of data generated at locations other than Fort Benning. It is necessary, therefore, to adjust the estimates made in Appendix C to allow for differences in climate and soil character between Fort Benning and the sites considered in Appendix C. The expected yields at Fort Benning and the planting density-harvest schedule combinations indicated for achieving them are shown in Table G-VI. Three yield ranges are given for each plant species shown in the table. The first of these is at the planting density-harvest schedule combination which is expected to produce the highest average annual yield per acre-year for the species at Fort Benning. Notice that for all the species shown, this when the stand is a year old. One of the other two ranges is for the planting density-harvest schedule combination which is expected to give the second highest yield if the first harvest is taken from the stand when it is a year old. The third range shown is the highest estimated yield from planting density-harvest schedule combinations in which the first harvest is taken from the stand when it is two years old.

For hybrid poplar, the yield estimates in Appendix C are based on data from State College, Pennsylvania. The growth potential estimates shown in Table G-II suggest that species well adapted to the Fort Benning locality should grow considerably more rapidly than similarly well-adapted species at State College. Therefore, for the bottomland sites at Fort Benning, it is concluded that hybrid poplar varieties well adapted to the site will produce yields at least as high as the most productive varieties at State College as estimated in Appendix C. However, the upland sites are not

expected to be quite as productive as the bottomland sites at Benning, because the soils at the former have a moderately lower water retention capacity than those of the latter. This probable difference in productivity is estimated to be about ten percent. The upper limit shown in the table for each of the hybrid poplar yield ranges is the upper limit of the estimated yield range for the bottomland sites. The lower limit for each of the ranges is the lower limit of the estimated yield range for the upland sites.

For eastern cottonwood, the yield estimates in Appendix C are based on data collected at Stoneville, Mississippi. Reference to Table G-II shows that the growth potential at Fort Benning is expected to be moderately lower than at the Mississippi site, but reference to Table G-III shows that rainfall during the growing season is likely to be more favorable at Fort Benning. It is concluded that the productivity of eastern cottonwoods well adapted to Fort Benning and the Mississippi sites will be about the same. The estimated yield ranges shown in Table G-VI are based on middle values between the high and low approximations in Appendix C for eastern cottonwood. The upper and lower limits of the ranges shown in the table have the same significance as is the case for hybrid poplar.

The yield estimates for sycamore shown in Table G-VI are derived in the same way as are the estimates for eastern cottonwood.

For Missouri cottonwood, the yield estimates in Appendix C for the Milford site in Kansas have been used as the basis for yield estimates from this species at Benning. The Milford estimates were chosen because the soil at Milford is a sandy loam and hence somewhat comparable with one of the two soil types likely to be used for plantations at Fort Benning. Fort Benning is expected to be considerably more productive than Milford, Kansas (see Tables G-II and G-III),but as noted in Appendix C, the estimates for Missouri

TABLE G-VI

PREDICTED YIELDS FROM VARIOUS DECIDUOUS SPECIES AND CORRESPONDING PLANTING DENSITIES AND HARVEST SCHEDULES FOR FORT BENNING

Species	Planting Area Ft^2 per Plant	Stand Age at 1st Harvest Years	Interval Between Harvests-Years	Estimated Average Annual Yield Tons (oven-dry) Per Acre-Year
Hybrid poplar	4	1	2	8.2 to 9.8
	6	1	2	7.8 to 9.1
	4	2	2	7.7 to 9.0
Eastern cottonwood	4	1	3	10.3 to 11.5
	4	1	2	9.9 to 11.0
	4	2	3	8.5 to 9.5
Sycamore	4	1	3	7.9 to 8.7
	6	1	3	7.8 to 8.7
	8	2	3	7.0 to 7.8
Missouri cottonwood	4	1	2	10.0 to 11.1
	6	1	3	9.5 to 10.5
	4	2	2	8.7 to 9.7

cottonwood are believed to be unrealistically high for Milford. Consequently, the estimates shown in Appendix C have been taken for Fort Benning without adjustment.

The estimates in Table G-VI for the two cottonwoods suggest that yields perhaps as high as ten to eleven tons (oven-dry basis) per acre-year might be possible at Fort Benning. However, these estimates are based on original data about which there are some uncertainties (see Appendix C). More confidence can be placed in the original data from which the hybrid poplar estimates are derived. Therefore, these latter estimates will be used for estimating the costs and other factors associated with plantation operation at Fort Benning. Specifically, it will be assumed that the highest average annual yield per acre of plant matter from a plantation at Fort Benning will be between 7.8 and 9.8 tons (oven-dry basis) per acre and that yields in this range will be achieved with a 4-1-2 planting density-harvest schedule combination.

V. OPERATIONAL DATA FOR ENERGY PLANTATIONS AT FORT BENNING

V.A. Introduction. The total fuel consumption in fixed facilities at Fort Benning in federal fiscal year 1973 was the equivalent of 2.5 x 10^{12} Btu. This fuel requirement will be used as the basis for estimated specifications for Energy Plantations at Fort Benning. If the fuel requirement is to be met with SNG produced from plant material, about 280,000 tons (oven-dry basis) of plant material will be needed per year. This requirement is based on the assumption that 4.45 standard cubic feet of SNG can be produced per oven-dry pound of plant material (see Appendix D, section II.D.). To grow this much material, seven 40,000 ton (oven-dry basis) plantation production units (see Appendix F, section V.B.3) will be required.

If the fuel requirements in fixed facilities at Fort Benning are to be met with solid fuel produced in the plantation, about 220,000 tons (oven-dry basis) will be needed every year. To produce this amount of material, five and a half plantation production units will be required.

V.B. Operational Data for a Plantation Production Unit. The procedure for estimating the area of a plantation production unit at Fort Benning, the machinery and manpower required to operate it and the associated costs is similar to that used for Fort Leonard Wood (see Appendix F, section V). The field machinery unit costs (Table F-IX, Appendix F) and pay rates for plantation personnel (Table F-X, Appendix F) used for Fort Leonard Wood will also be used for Fort Benning. It will be assumed that a supervisory team having the same skill composition and number of people (five) as recommended for plantations at Fort Leonard Wood will also be satisfactory for plantations at Fort Benning.

V.B.1. Plantation Size and Characteristics. The basic characteristics of a plantation production unit having a capacity of 40,000 tons (oven-dry basis) per year operated on a 4-1-2 planting density-harvest schedule combination are shown in Table G-VII. The estimates have been generated assuming that a hybrid poplar is the species grown. Estimates are shown at three plantation productivity levels, namely 7.8 tons (oven-dry basis) per acre-year (the "low" estimate), 8.8 tons per acre-year (the "medium" estimate) and 9.8 tons per acre-year (the "high" estimate).

V.B.2. Operational Data for a 40,000-Ton-per-Year Plantation Production Unit.

V.B.2.a. Supervisory Team. The estimated annual cost of the supervisory team is shown in Table G-VIII. This cost is divided between seven plantation production units if raw material for SNG is being grown, and between five and a half units if solid fuel is being produced.

V.B.2.b. Field Operations. The estimated capital and annual costs of field operations for a plantation production unit producing raw material for making SNG are shown in Table G-IX. The costs for a unit producing solid fuel are shown in Table G-X.

Because of the more favorable climate at Fort Benning than at Fort Leonard Wood, the planting season at Benning will run from March to June rather than from April to June as is the case at Fort Leonard Wood. This factor and the smaller area to be planted at Fort Benning because of the higher yields per acre-year there than at Fort Leonard Wood cause the estimated annual cost of planting at Benning to be less than at Leonard Wood.

The equipment required for harvesting and the estimated annual cost of harvesting per plantation production unit are the same at Forts Benning and Leonard Wood because the harvester capacity and harvesting cost are controlled by the amount to be harvested and not the area to be harvested. The cost

TABLE G-VII

CHARACTERISTICS OF A PLANTATION PRODUCTION UNIT AT FORT BENNING HAVING AN ANNUAL CAPACITY OF 40,000 TONS (OVEN-DRY BASIS) OF PLANT MATERIAL[1]

Operational Element	Productivity-Tons (o.d.) per Acre-Year		
	7.8	8.8	9.8
Planting area per plant-A (ft^2)	4	4	4
Age at first harvest-n_1 years	1	1	1
Interval between harvests-n_2 years	2	2	2
Yields: First harvest-o.d. T/acre	1.05	1.15	1.25
Subsequent harvests-o.d. T/acre	16.95	19.13	21.31
Average annual-o.d. T/acre-year	7.8	8.8	9.8
Number of clones planted per acre	10,890	10,890	10,890
Number of surviving plants at year 1	10,520	10,520	10,520
Number of harvests after the first-m	5	5	5
Number of clones per plant-c	10	10	10
Area of a planting area - a acres	467	414	375
Area of a plantation production unit-acres	5,137	4,554	4,125
Area harvested per year - acres	2,802	2,484	2,250
Number of clones needed/year (thousands)	5,086	4,508	4,084
Area cultivated per year - acres	4,903	4,347	3,937
Tractor-months required for cultivation per year	6.5	5.8	5.2
Fungicide application area per year - acres	700	621	562
Tractor-months required per year for fungicide	0.93	0.82	0.75
Planting tractor-months required	7.4	6.6	6.0
Area limed per year - acres	2,802	2,484	2,250
Lime required yearly - tons	1,401	1,242	1,125
Area cleared per year for replanting - acres	467	414	375
Tractor-months required for clearing	2.5	2.3	2.2
Man-months required for clone production per year	25	22	20
Fertilizer required per year - tons	552	552	552
Tractor-months for fertilizing per year	9.8	8.7	7.8

Footnote:

1. Based on growing a hybrid poplar well adapted to Fort Benning on a 4-1-2 planting density-harvest schedule combination.

of transporting the spent sludge from the SNG plant and spreading the sludge on the plantation are also the same at the two army bases. The equipment required for, and the estimated annual costs of, the other field operations are plantation-area dependent, and hence lower at Fort Benning than at Fort Leonard Wood.

V.B.2.c. Clone Production. Clone gathering and storing will be done during the fall and winter months. The estimated capital and annual operating costs for these operations are shown in Table G-XI. Clone production costs per plantation production unit are the same for producing solid fuel and raw material for SNG.

V.B.2.d. Motor Pool. The estimated capital and annual operating costs of the motor pool are shown in Table G-XII for a plantation producing 280,000 tons (oven-dry basis) per year of plant material for making SNG at Fort Benning. Comparable costs for a plantation producing 220,000 tons (oven-dry basis) per year of plant material for use as solid fuel are shown in Table G-XIII.

V.B.3. Plantation Establishment. The estimated operational programs for establishing plantation production units at three plantation productivity levels at Fort Benning to be operated on a 4-1-2 planting density-harvest schedule combination are shown in Table G-XIV. These programs are based on the same considerations used for defining plantation establishment programs at Fort Leonard Wood (see Appendix F, section V.C.3.).

The estimated costs, by years, for establishing plantation production units at Fort Benning are shown in Table G-XV. These estimates are based on the assumption that the plantation will consist of seven plantation production

TABLE G-VIII

ESTIMATED ANNUAL COST OF THE SUPERVISORY TEAM*

Cost Element	Annual Cost $ Per Year
Payroll:	
1 General foreman	22,000
1 Horticulturist	18,000
1 Assistant foreman	11,000
1 Motor pool foreman	15,000
1 Secretary-dispatcher	6,500
Subtotal	72,500
Payroll fringe benefits	14,500
Maintenance and repair costs:	
4 pickup trucks	1,100
Fuel-gasoline	
10,600 gallons per year	5,100
Miscellaneous supplies and services:	24,000
Equipment replacement:	
4 pickup trucks	4,500
Total Annual Operating Cost:	$121,000

* The annual cost is divided between seven plantation production units if raw material for SNG is being produced, and 5.5 units if solid fuel is being grown.

TABLE G-IX

ESTIMATED CAPITAL AND ANNUAL OPERATING COSTS FOR FIELD OPERATIONS AT A PLANTATION PRODUCTION UNIT AT FORT BENNING PRODUCING RAW MATERIAL FOR SNG

Machinery & Supplies		#	Capital Cost $	Maintenance Repair $/Year	Fuel Consumption Gallons/Year		Fuel Cost $/Year	Supplies $/Year	Equipment Replacement $/Year	Payroll[1] $/Year
					Gasoline	Diesel				
Harvesters		5	250,000	40,000	-	24,180	7,260	-	50,000	54,600
Chip trucks		5	83,500	3,700	22,980	-	11,040	-	15,850	45,000
Dumpwagons		7	35,000	3,500	-	-	-	-	4,375	-
Tractors		2	24,000	2,000	-	6,480	1,944	-	4,000	15,600
Sludge Trucks		4	70,000	2,960	18,384	-	8,832	-	13,000	36,000
Tractors	L[2]	2.5	30,000	2,500	-	4,004	1,201	-	5,000	9,750
	M[3]	2.5	30,000	2,500	-	3,569	1,071	-	5,000	8,593
	H[4]	2	24,000	2,000	-	3,226	968	-	4,000	7,800
4-row cultivator		2	4,000	900	-	-	-	-	800	-
2-row planter	L	2	2,200	200	-	-	-	-	146	7,992
	M	2	2,200	200	-	-	-	-	146	7,128
	H	2	2,200	200	-	-	-	-	146	6,480
Sprayer		2/7	743	114	-	-	-	-	149	-
Crawler	L	2/7	9,429	1,714	-	2,372	712	-	1,571	1,725
	H	2/7	9,429	1,714	-	2,183	655	-	1,571	1,587
	M	2/7	9,429	1,714	-	2,089	626	-	1,571	1,518
Lime[5]	L	-	-	-	-	-	-	14,010	-	-
	M	-	-	-	-	-	-	12,420	-	-
	H	-	-	-	-	-	-	11,250	-	-
Fungicide[6]	L	-	-	-	-	-	-	7,000	-	-
	M	-	-	-	-	-	-	6,210	-	-
	H	-	-	-	-	-	-	5,620	-	-

TABLE G-IX

(continued)

ESTIMATED CAPITAL AND ANNUAL OPERATING COSTS FOR FIELD OPERATIONS

AT A PLANTATION PRODUCTION UNIT AT FORT BENNING

PRODUCING RAW MATERIAL FOR SNG

Machinery & Supplies	#	Capital Cost $	Maintenance Repair $/Year	Fuel Consumption Gallons/Year Gasoline	Fuel Consumption Gallons/Year Diesel	Fuel Cost $/Year	Supplies $/Year	Equipment Replacement $/Year	Payroll[1] $/Year
Small tools & general supplies	-	-	-	-	-	-	5,000	-	-
Totals L	-	508,872	57,588	41,364	37,036	30,989	26,040	94,891	170,667
M	-	508,872	57,588	41,364	36,412	30,802	23,630	94,891	168,508
M	-	502,872	57,088	41,364	35,975	30,670	21,870	94,891	166,998
Per ton Harvested L	-	-	$1.44	1.03[7]	0.93[7]	$0.77	$0.65	$2.37	$4.27
M	-	-	1.44	1.03[7]	0.91[7]	0.77	0.59	2.37	4.27
H	-	-	1.43	1.03[7]	0.90[7]	0.77	0.55	2.35	4.17

Footnotes:

1. Including fringe benefits
2. L = low-yield plantation
3. M = medium-yield plantation
4. H = high-yield plantation
5. One-half ton per acre at $10 per ton delivered and applied
6. $10 per acre
7. Gallons per ton of plant material harvested.

TABLE G-X

ESTIMATED CAPITAL AND ANNUAL OPERATING COSTS FOR FIELD OPERATIONS

AT A PLANTATION PRODUCTION UNIT AT FORT BENNING

PRODUCING SOLID FUEL

Machinery & Supplies	#	Capital Cost $	Maintenance Repair $/Year	Fuel Consumption Gallons/Year Gasoline	Fuel Consumption Gallons/Year Diesel	Fuel Cost $/Year	Supplies $/Year	Equipment Replacement $/Year	Payroll[1] $/Year
Harvesters	5	250,000	40,000	-	24,180	7,260	-	50,000	54,600
Chip trucks	5	83,500	3,700	22,980	-	11,040	-	15,850	45,000
Dumpwagons	7	35,000	3,500	-	-	-	-	4,375	-
Tractors	2	24,000	2,000	-	6,480	1,944	-	4,000	15,600
Tractors L[2]	3	36,000	3,000	-	6,650	1,995	-	6,000	16,010
M[3]	3	36,000	3,000	-	5,918	1,776	-	6,000	14,248
H[4]	2.5	30,000	2,500	-	5,332	1,600	-	5,000	12,837
4-row cultivator	2	4,000	900	-	-	-	-	800	-
2-row planter L	2	2,200	200	-	-	-	-	146	7,992
M	2	2,200	200	-	-	-	-	146	7,128
H	1.5	1,650	150	-	-	-	-	110	6,480
Sprayer	2/6	867	133	-	-	-	-	173	-
2-row side-dresser L	2	1,000	200	-	-	-	-	200	-
M	2	1,000	200	-	-	-	-	200	-
H	1.5	750	150	-	-	-	-	150	-
Crawler L	2/6	11,000	2,000	-	2,372	712	-	1,833	1,725
M	2/6	11,000	2,000	-	2,183	655	-	1,833	1,587
H	2/6	11,000	2,000	-	2,089	626	-	1,833	1,518
Lime[5] L	-	-	-	-	-	-	14,010	-	-
M	-	-	-	-	-	-	12,420	-	-
H	-	-	-	-	-	-	11,250	-	-

TABLE G-X

(continued)

ESTIMATED CAPITAL AND ANNUAL OPERATING COSTS FOR FIELD OPERATIONS

AT A PLANTATION PRODUCTION UNIT AT FORT BENNING

PRODUCING SOLID FUEL

Machinery & Supplies	#	Capital Cost $	Maintenance Repair $/Year	Fuel Consumption Gallons/Year Gasoline	Fuel Consumption Gallons/Year Diesel	Fuel Cost $/Year	Supplies $/Year	Equipment Replacement $/Year	Payroll[1] $/Year
Fungicide[6] L	-	-	-	-	-	-	7,000	-	-
M	-	-	-	-	-	-	6,210	-	-
H	-	-	-	-	-	-	5,620	-	-
Fertilizer	-	-	-	-	-	-	93,840	-	-
Small tools & general supplies	-	-	-	-	-	-	5,000	-	-
Totals L	-	447,567	55,633	22,980	39,682	22,951	119,850	83,377	140,927
M	-	447,567	55,633	22,980	38,761	22,675	117,470	83,377	138,163
H	-	440,767	55,033	22,980	38,081	22,470	115,710	82,291	136,035
Per ton harvested L	-	-	$1.39	0.57[7]	0.99[7]	$0.57	$3.00	$2.08	$3.52
M	-	-	1.39	0.57[7]	0.97[7]	0.57	2.94	2.08	3.45
H	-	-	1.38	0.57[7]	0.95[7]	0.56	2.89	2.06	3.40

Footnotes:
1. Including fringe benefits.
2. L = low-yield plantation.
3. M = medium-yield plantation
4. H = high-yield plantation
5. One-half ton per acre at $10 per ton delivered and applied.
6. $10 per acre.
7. Gallons per ton of plant material harvested.

units, and hence have the capacity required for producing 280,000 tons (oven-dry basis) of plant material per year. The costs of establishing a plantation production unit in a plantation having an annual capacity of 220,000 tons (the amount needed for solid fuel at Fort Benning) are slightly higher than those shown in Table G-XV, but the differences are small. The cost estimates in Table G-XV do not include the capital cost of the machinery, equipment and facilities required--they cover only the work necessary for establishing a plantation production unit.

Comparison of the estimated costs of establishing a plantation production unit at Fort Benning with those for a similar unit at Fort Leonard Wood (see Table F-XXII in Appendix F) show that the costs are moderately lower at Fort Benning. The difference in costs is almost entirely due to the higher average annual yields of plant material per acre expected from plantations at Fort Benning than from plantations in the Fort Leonard Wood area. The land area required per plantation production unit is, therefore, smaller at Fort Benning than at Fort Leonard Wood (4,554 acres versus 4,840 acres for medium-productivity plantations, for instance). Since most of the plantation establishment costs are determined by the area of a plantation production unit, it follows that establishment costs should be lower at Fort Benning than at Fort Leonard Wood.

<u>V.B.4. Cost of Energy Plantations for Fort Benning</u>. The estimated costs of establishing and equipping Energy Plantations at Fort Benning having an annual capacity of 280,000 tons (oven-dry basis) of plant material for SNG production at three plantation productivity levels are shown in Table G-XVI. The plantation consists of seven plantation production units. The costs incurred in establishing the plantation are based on the estimates shown in Table G-XV for one plantation production unit. The equipment and facility

TABLE G-XI

ESTIMATED CAPITAL AND ANNUAL OPERATING COSTS FOR CLONE PRODUCTION FOR A PLANTATION PRODUCTION UNIT AT FORT BENNING

Machinery & Supplies	#	Capital Cost $	Maintenance Repair $/Year	Fuel Consumption Gallons/Year Gasoline	Fuel Consumption Gallons/Year Diesel	Fuel Cost $/Year	Supplies $/Year	Equipment Replacement $/Year	Payroll[1] $/Year
Pickup truck	1	5,600	270	576	-	276	-	1,120	-
Wagon	1	2,300	75	-	-	-	-	153	-
Building L[2]	1	6,900	100	-	-	-	-	345	13,500
M[3]	1	6,200	100	-	-	-	-	310	11,880
H[4]	1	5,600	100	-	-	-	-	280	10,800
Supplies L	-	-	-	-	-	-	3,200	-	-
M	-	-	-	-	-	-	2,900	-	-
H	-	-	-	-	-	-	2,600	-	-
Totals L		14,800	445	576	-	276	3,200	1,618	13,500
M		14,100	445	576	-	276	2,900	1,583	11,880
H		13,500	445	576	-	276	2,600	1,553	10,800
Per ton harvested L	-	-	$0.01	0.01[5]	-	$0.01	$0.08	$0.04	$0.34
M	-	-	0.01	0.01[5]	-	0.01	0.07	0.04	0.30
H	-	-	0.01	0.01[5]	-	0.01	0.07	0.04	0.27

Footnotes:
1. Including fringe benefits.
2. L = low-yield plantation.
3. M = medium-yield plantation.
4. H = high-yield plantation
5. Gallons per ton of plant material harvested.

costs are based on the capital costs shown in Tables G-IX, G-XI, and G-XII and on the cost of four pickup trucks (see Table F-IX, Appendix F) required for the supervisory team described in Table G-VIII.

The estimated annual costs of operating plantations at each of the three productivity levels are also shown in Table G-XVI. These operating costs are based on the annual costs shown in Tables G-VIII, G-IX, G-XI and G-XII.

The estimated costs of establishing, equipping and operating plantations producing solid fuel for Fort Benning at three plantation productivities are shown in Table G-XVII. The annual capacities of the plantations are 220,000 tons (oven-dry basis) of plant material. Five and a half plantation production units are required for this annual capacity.

The plantation establishment costs shown in Table G-XVII are based on the estimates shown in Table G-XV. The equipment and facility costs are based on the capital costs shown in Tables G-X, G-XI and G-XIII and on the cost of four pickup trucks (see Table F-IX, Appendix F) required for the supervisory team defined in Table G-VIII.

The estimated annual costs of operating plantations at the productivities shown in Table G-XVII are based on the annual plantation operating costs shown in Tables G-VIII, G-X, G-XI and G-XIII.

TABLE G-XII

ESTIMATED CAPITAL AND ANNUAL OPERATING COSTS FOR THE MOTOR POOL

FOR A PLANTATION PRODUCING 280,000 TONS (OVEN-DRY BASIS) OF PLANT MATERIAL FOR SNG AT FORT BENNING

Machinery & Supplies	#	Capital Cost $	Maintenance Repair $/Year	Fuel Consumption Gallons/Year Gasoline	Fuel Consumption Gallons/Year Diesel	Fuel Cost $/Year	Supplies $/Year	Equipment Replacement $/Year	Payroll[1] $/Year
Pickup truck	1	5,600	270	2,300	-	1,104	-	1,120	84,000
Building & equipment	1	140,000	3,500	-	-	-	-	7,000	-
Replacement:									
Harvester	3	150,000	-	-	-	-	-	30,000	-
Chip truck	3	50,100	-	-	-	-	-	9,510	-
Sludge truck	3	52,500	-	-	-	-	-	9,750	-
Tractor	3	36,000	-	-	-	-	-	6,000	-
Pickup truck	1	5,600	-	-	-	-	-	1,120	-
Dumpwagon	6	30,000	-	-	-	-	-	3,750	-
Totals	-	469,800	3,770	2,300	-	1,104	-	68,250	84,000
Per ton harvested	-	-	$0.01	0.01[2]	-	$0.01	-	$0.24	$0.30

Footnotes:
1. Including fringe benefits.
2. Gallons per ton of plant material harvested.

TABLE G-XIII

ESTIMATED CAPITAL AND ANNUAL OPERATING COSTS FOR THE MOTOR POOL FOR A PLANTATION PRODUCING 220,000 TONS (OVEN-DRY BASIS) OF PLANT MATERIAL FOR SOLID FUEL AT FORT BENNING

Machinery & Supplies	#	Capital Cost $	Maintenance Repair $/Year	Fuel Consumption Gallons/Year Gasoline	Diesel	Fuel Cost $/Year	Supplies $/Year	Equipment Replacement $/Year	Payroll[1] $/Year
Pickup truck	1	5,600	270	2,300	-	1,104	-	1,120	72,000
Building & equipment	1	120,000	3,500	-	-	-	-	6,000	-
Replacement:									
Harvester	3	150,000	-	-	-	-	-	30,000	-
Chip truck	3	50,100	-	-	-	-	-	9,510	-
Tractor	3	36,000	-	-	-	-	-	6,000	-
Pickup truck	1	5,600	-	-	-	-	-	1,120	-
Dumpwagon	5	25,000	-	-	-	-	-	3,125	-
Totals		392,300	3,770	2,300	-	1,104	-	56,875	72,000
Per ton harvested	-	-	$0.02	0.01[2]	-	$0.01	-	$0.26	$0.33

Footnotes:
1. Including fringe benefits.

2. Gallons per ton of plant material harvested.

Preceding page blank

TABLE G-XIV

OPERATIONAL PROGRAMS FOR ESTABLISHING PLANTATION PRODUCTION UNITS AT FORT BENNING TO BE OPERATED AT A 4-1-2 PLANTING DENSITY-HARVEST SCHEDULE COMBINATION

Year	Operation	Plantation Productivity[1] Low	Medium	High
1	Acres to be cleared-6 planting areas	2,802	2,484	2,250
	Acres to be planted-1 planting area	467	414	375
	Number of clones to buy (thousands)	5,086	4,508	4,084
	Tractor-months to clear land	10.8	9.6	8.7
	Tractor-months to cultivate-5 unplanted areas	12.0	10.7	9.7
	Tractor-months to plant clones	7.4	6.6	6.0
	Tractor-months to cultivate-1 planted area	1.9	1.6	1.5
	Fertilizer per planting area-tons	2.70	2.62	2.58
	Tractor-months to fertilize-1 planting area	1.6	1.4	1.3
	Lime required per planting area-tons	234	207	188
	Number of clones needed for year 2 (thousands)	25,428	22,542	20,419
	Team-months needed to produce clones	41.0	36.3	33.0
	Plant material harvested-o.d. tons	237	230	226
	Harvester-months for harvesting	0.35	0.34	0.34
2	Acres to be cleared-5 planting areas	2,335	2,070	1,875
	Acres to be planted-5 planting areas	2,335	2,070	1,875
	Tractor-months to clear land	9.0	8.0	7.2
	Tractor-months to cultivate cleared land	10.0	8.9	8.0
	Tractor-months to plant clones	37.0	33.0	30.0
	Tractor-months to cultivate planted area	11.1	9.8	8.9
	Fertilizer for 6 planting areas-tons	35.3	34.9	34.9
	Tractor months for fertilizing	9.8	8.7	7.8
	Lime for 5 planting areas-tons	1,168	1,035	938
	Team-months for clone production	41.0	36.3	33.0
	Plant material harvested-tons o.d.	4,361	4,291	4,271
	Harvester-months for harvesting	6.5	6.5	6.4
3	Acres to be planted-5 planting areas	2,335	2,070	1,875
	Tractor-months to plant clones	37.0	33.0	30.0
	Tractor-months to cultivate planted areas	11.1	9.8	8.9
	Fertilizer for 11 planting areas	49	48	48
	Tractor-months for fertilizing	17.9	15.8	14.4
	Lime for 5 planting areas-tons	1,168	1,035	938
	Plant material harvested-o.d. tons	4,361	4,291	4,271
	Harvester-months for harvesting	6.5	6.5	6.4

Footnote:

1. Assuming hybrid poplars well adapted to the Fort Benning region are to be planted. A low-productivity plantation is expected to have an average annual sustained harvestable yield of 7.8 tons (oven-dry basis) per acre-year. The corresponding yields in plantations of medium and high productivity are expected to be 8.8 and 9.8 tons per acre-year, respectively.

Preceding page blank

TABLE G-XV

ESTIMATED COSTS OF ESTABLISHING PLANTATION PRODUCTION UNITS OPERATED ON A 4-1-2 PLANTING DENSITY-HARVEST SCHEDULE COMBINATION AT FORT BENNING[1]

Year	Operation	Plantation Productivity[2]		
		Low	Medium	High
1	Land clearing	$ 20,876	$ 18,557	$ 16,817
	Land preparation	12,624	11,256	10,204
	Clones purchased	50,856	45,085	40,838
	Clone planting	15,355	13,695	12,450
	Cultivating planted area	1,946	1,715	1,557
	Fertilizer	314	277	252
	Fertilizer application	1,614	1,434	1,295
	Lime @ $10/ton delivered & spread	2,340	2,070	1,880
	Clone production	103,197	91,367	83,061
	Supervision-payroll & fringe benefits	7,971	7,971	7,971
	Supervision-other costs	1,214	1,214	1,214
	Motor pool-payroll & fringe benefits	1,714	1,714	1,714
	Motor pool-other costs	625	625	625
	Harvesting	886	861	861
	Totals - Year 1	$221,532	$197,841	$180,739
2	Land clearing	$ 17,397	$ 15,464	$ 13,918
	Land preparation	10,520	9,363	8,416
	Planting	76,775	68,475	62,250
	Cultivating planted area	11,677	10,310	9,363
	Fertilizer	6,001	5,933	5,933
	Fertilizer application	9,761	8,665	7,769
	Lime @ $10/ton delivered & spread	11,680	10,350	9,380
	Clone production	103,197	91,367	83,061
	Harvesting	16,553	16,325	16,198
	Supervision-payroll & fringe benefits	10,200	10,200	10,200
	Supervision-other costs	3,033	3,033	3,033
	Motor pool-payroll & fringe benefits	3,429	3,429	3,429
	Motor pool-other costs	1,250	1,250	1,250
	Totals - Year 2	$281,473	$254,164	$234,200

TABLE G-XV (continued)

ESTIMATED COSTS OF ESTABLISHING PLANTATION PRODUCTION UNITS OPERATED ON A 4-1-2 PLANTING DENSITY-HARVEST SCHEDULE COMBINATION AT FORT BENNING[1]

Year	Operation	Plantation Productivity[2] Low	Medium	High
3	Planting	$ 76,775	$ 68,475	$ 62,250
	Cultivation planted & harvested area	11,677	10,310	9,363
	Fertilizer	8,330	8,160	8,160
	Fertilizer application	17,828	15,737	14,342
	Lime @ $10/ton delivered & spread	11,680	10,350	9,380
	Harvesting	16,553	16,325	16,198
	Supervision-payroll & fringe benefits	12,429	12,429	12,429
	Supervision-other costs	4,854	4,854	4,854
	Motor pool-payroll & fringe benefits	5,143	5,143	5,143
	Motor pool-other costs	1,875	1,875	1,875
	Totals - Year 3	$167,144	$153,658	$143,994
	GRAND TOTAL - 3 Years	$670,149	$605,663	$558,933

Footnotes:

1. The costs shown in this table do not include the capital cost of the field machinery and facilities required for the plantation production units. The costs shown assume that the plantation will consist of seven plantation production units.

2. Assuming hybrid poplars well adapted to the Fort Benning region are to be planted. A low-productivity plantation is expected to have an average annual sustained harvestable yield of 7.8 tons (oven-dry basis) per acre-year. The corresponding yields in plantations of medium and high productivity are expected to be 8.8 and 9.8 tons per acre-year, respectively.

TABLE G-XVI

ESTIMATED COSTS OF ESTABLISHING, EQUIPPING AND OPERATING PLANTATIONS ON A 4-1-2 PLANTING DENSITY-HARVEST SCHEDULE COMBINATION AT FORT BENNING

Plantation Capacity: 280,000 tons (oven-dry basis) per year for SNG production.

Cost Factor	Plantation Productivity		
	Low	Medium	High
Plantation Establishment:			
• First year	$1,551,000	$1,385,000	$1,265,000
• Second year	1,970,000	1,779,000	1,639,000
• Third year	1,170,000	1,076,000	1,008,000
Subtotal:	$4,691[illegible]0	$4,240,000	$3,912,000
Equipment and Facilities:	4,158,000	4,153,000	4,149,000
Total Plantation Cost:	$8,849,000	$8,393,000	$8,061,000

Annual Operating Costs:			
• Payroll & fringe benefits	$1,460,000	$1,434,000	$1,416,000
• Other operating costs	865,000	845,000	826,000
• Equipment replacement cost	748,000	748,000	741,000
• Plantation maintenance cost	141,000	127,000	117,000
Total Annual Operating Costs	$3,214,000	$3,154,000	$3,100,000
Operating Cost Per Ton (oven-dry basis)	$11.48	$11.26	$11.07

Preceding page blank

TABLE G-XVII

ESTIMATED COSTS OF ESTABLISHING, EQUIPPING AND OPERATING PLANTATIONS ON A 4-1-2 PLANTING DENSITY-HARVEST SCHEDULE COMBINATION AT FORT BENNING

Plantation capacity: 220,000 tons (oven-dry basis) per year for solid fuel.

Cost Factor	Plantation Productivity		
	Low	Medium	High
Plantation Establishment:			
• First year	$1,218,000	$1,088,000	$ 944,000
• Second year	1,548,000	1,398,000	1,288,000
• Third year	919,000	845,000	792,000
Subtotal:	$3,685,000	$3,331,000	$3,024,000
Equipment and Facilities:	2,958,000	2,954,000	2,913,000
Total Plantation Cost:	$6,643,000	$6,285,000	$5,937,000
Annual Operating Costs:			
• Payroll & fringe benefits	$1,008,000	$ 984,000	$ 967,000
• Other operating costs	1,147,000	1,131,000	1,115,000
• Equipment replacement cost	529,000	529,000	522,000
• Plantation maintenance cost	111,000	100,000	92,000
Total Annual Operating Costs	$2,795,000	$2,744,000	$2,696,000
Operating Cost Per Ton (oven-dry basis)	$12.70	$12.47	$12.25

Preceding page blank

VI. SENSITIVITY ANALYSIS

VI.A. Introduction. The sensitivity analysis described in Appendix F, section VI shows that when a plantation is operated to produce its highest yield of plant material per acre-year, it is not producing the plant material at its lowest cost. For a plantation being operated at a planting density of four square feet per plant, and a harvest schedule in which the first harvest from the stand is taken when the stand is a year old and the interval between harvests is two years (the combination which leads to the highest yields per acre-year at Fort Benning), the cost of plant material can be reduced between five and ten percent by increasing the interval between harvests or by decreasing the planting density. However, the "penalty" for these operating cost benefits is an increase of about ten percent in the plantation area needed for producing a given amount of plant material. The cost of establishing and equipping the plantation may, however, be reduced by five to about fifteen percent. There are, therefore, a number of trade-off possibilities if a penalty in plantation area is tolerable in exchange for a reduction in plantation capital and operating costs.

VI.B. Influence of Planting Density-Harvest Schedule Combinations. In principle, there are four factors which can be varied--the age of the stand at first harvest, the interval between harvests, the total number of harvests taken from a stand and the planting density.

The first harvest from a planting does not produce much of a yield, but the plant material is specially suitable for clone production. There is little benefit possible, therefore, from taking the first harvest from a stand before the stand is a year old. On the other hand, to delay the first harvest until the stand is over a year old has almost no effect on the cost of plant material produced from the stand over a series of harvests, but does increase plantation

Preceding page blank

area and establishment costs. Consequently, from a practical point of view, there are no benefits likely to come from taking the first harvest from a stand at any age other than one year old.

If the total number of harvests from a stand can be extended beyond six without adversely affecting the average annual sustained yield from the stand, sensitivity analysis suggests that the cost of plant material would be reduced five percent or so with little or no effect on the plantation area and establishment cost. At present, however, this option cannot be counted on to reduce the cost of plant material because there are no data available on the effect of more than six harvests on the average annual sustained yield from the stand.

From a practical point of view, the two variables which can be counted on to have the most effect on costs and required plantation area are the planting density and interval between harvests. Sensitivity analysis shows that increasing the interval between harvests from two to three years while making no other changes will reduce the plant material and plantation establishment costs by about five percent each, but increase the necessary plantation area by about twelve percent (see Appendix F, section VI). On the other hand, if the planting density is decreased to one plant per eight square feet from one per four square feet, the cost of plant material can be reduced by about seven percent, the plantation establishment cost by twelve percent or so, and the plantation area is increased by only about eight percent. If the planting density and interval between harvests are both changed in a plantation having an annual capacity of 280,000 tons (oven-dry basis) for SNG from a 4-1-2 to an 8-1-3 combination, estimated plantation costs at Fort Benning will be altered to the following:

	Production Plan		Change Percent
	4-1-2	8-1-3	
Cost of plant material per o.d. ton	$11.26	$10.40	-8
Cost of establishing & equipping plantation	$8,390,000	$7,000,000	-17
Required plantation area - acres	31,900	35,400	+11

The 8-1-3 production plan leads to about the lowest costs believed possible at Fort Benning, and is recommended for that Army base if land is available for the larger plantation site.

VII. CONCLUSIONS

Deciduous tree species are recommended for plantations at Fort Benning. The growing season is not long enough to make any warm-season grass species practical. Assuming that the plantation can be established in the Ochlockenee bottomland and sandy loam upland soils at the fort, the character of these soils and the local climate are such that plantation yields of plant material per acre-year are likely to be among the highest that can be expected at any major troop training center in a locality suitable for Energy Plantations. The maximum average annual sustained plant-material yields attainable at Fort Benning are expected to be between 7.8 and 9.8 tons (oven-dry basis) per acre-year, the most probable yield being about 8.8 tons.

Several species of deciduous trees are recommended for the Fort Benning area (see Table G-IV). It is estimated that the highest average annual yields will be achieved with a planting density of four square feet per plant, the first harvest when the stand is a year old, and a two-year interval between harvests. Plant material will be produced at the lowest cost with a planting density of eight square feet per plant, the first harvest when the stand is a year old, and three-year intervals between harvests.

The estimated annual plant-material requirements, plantation areas and associated costs for meeting the fuel requirements of the fixed facilities at Fort Benning with SNG or solid fuel from plantations having a productivity of 8.8 tons (oven-dry basis) per acre-year are summarized in Table G-XVIII.

Preceding page blank

TABLE G-XVIII

SUMMARY OF ESTIMATES FOR ENERGY PLANTATIONS AT FORT BENNING

Basis: - medium-yield plantations - 8.8 tons (oven-dry basis) per acre-year
- 280,000 tons (oven-dry basis) required per year for SNG, and 220,000 tons for solid fuel

		Raw Material for SNG			Solid Fuel		
	Harvest Schedule	Plant Material $ Per O.D. Ton	Plantation Area Acres	Plantation Cost[1]-$	Plant Material $ Per O.D. Ton	Plantation Area Acres	Plantation Cost[1]-$
Plantations having minimum area:	4-1-2	$11.26	31,900	$8,393,000	$12.47	25,000	$6,285,000
Plantations having lowest production cost:	8-1-3	$10.40	35,400	$7,000,000	$11.52	27,800	$5,200,000

Footnote:

1. Cost of establishing and equipping the plantation.

Preceding page blank

VII. REFERENCE LIST

1. Climatic Atlas of the United States, Environmental Science Services Administration, Environmental Data Service, U.S. Department of Commerce, June 1968.

2. Climatography of the United States No. 81 (by State), National Climatic Center, U.S. Department of Commerce, Asheville, N.C., August 1973.

3. Monthly Normals of Temperature, Precipitation and Heating and Cooling Degree-Days - 1941 to 1970, National Climatic Center, U.S. Department of Commerce, Asheville, N.C., August 1973.

4. C. A. Mohn, W. K. Randall and J. S. McKnight, Fourteen Cottonwood Clones Selected for Midsouth Timber Production - U. S. Department of Agriculture, Forest Service Research Paper 50-62, Southern Forest Experiment Station, 1970.

APPENDIX H

CLIMATE, TOPOGRAPHY, AND SOILS AT FORTS LEONARD WOOD AND BENNING

TABLE OF CONTENTS

I. FORT LEONARD WOOD

I.A. Introduction. Two members of InterTechnology's staff visited the locality of Fort Leonard Wood in the week of 22 July 1974. On the twenty-second, one of InterTechnology's personnel met with the following four locally knowledgeable persons and discussed topography, climate, soils structure, plant species and other matters pertinent to consideration of Energy Plantations on the fort or in its immediate vicinity:

Jay R. Law - U.S. Forest Service in Missouri
Jerry Gott - soil scientist with the U.S. Forest Service in Missouri
Mack Miller - soil scientist with the U.S. Forest Service in Missouri
Neal Morrison - Assistant Ranger, Rolla Ranger District.

On the twenty-third, both of the InterTechnology people spent essentially all day touring and inspecting the terrain surrounding the fort with Gott, Miller and Harold Dunn, who is Area 4 (in Missouri) District Conservationist with the U.S. Soil Conservation Service. One of the two people from InterTechnology who made this inspection trip arrived at, and left from, Fort Leonard Wood by air in daylight. He was able to view those areas on the fort to the northeast and southwest of the airstrip quite clearly from the plane during landing and take-off.

On the twenty-fourth, one of InterTechnology's people met with James McCall, Agronomy Specialist at the University of Missouri Extension Service. He provided general and independent confirmation of the information from Law, Gott, Miller, Morrison and Dunn.

The information specific to Fort Leonard Wood and its immediate environs collected during this three-day visit, and the conclusions drawn therefrom are the subjects of this section of the appendix.

Many of the findings from the trip are summarized in three sketch maps of the fort (see pages H-15, H-17, and H-19).

I.B. Topography. Fort Leonard Wood is located in south-central Missouri in the Missouri Ozark region. Typically throughout the region, the topography is a series of broad rolling uplands dissected by streams and creeks running through moderately steep valleys. The bottomlands in the valleys are generally narrow.

At Fort Leonard Wood, there are two creeks, the Big Piney on the east and the Roubidoux on the west. They flow generally northwards near the east and west boundaries of the fort, respectively. They are separated by a ridge of higher ground, which also runs approximately north and south.

I.C. Soils. The soil structures at the fort and in its immediately surrounding area fall into three distinct classes, namely "flat ridge top", "sloping hillside", and "bottomland".

I.C.1. Flat-Ridge-Top Soils. Soils in the flat-ridge-top category are generally of the Hobson or Lebanon series and are to be found, for instance, on the top of the ridge between the two main creeks on the fort (see Figure H-II). The soil is a shallow layer of silt or clay loam, often containing a substantial fraction of gravel or chert, overlaying a fragipan. The latter, which is also known as a perch water-table, is a dense, water-impervious layer often about two feet below the surface in the Fort Leonard Wood region. Because

of this fragipan, during the winter and early spring when soil moisture depletion by evaporation and plant transpiration is low, the soil in the flat-ridge-top regions often becomes extremely wet, even though it can hold only between about two and three and a half inches of water. As a consequence, regions having this soil structure are the least accessible on the fort to machinery in winter and early spring. In the summertime, and again because the fragipan is only about two feet below the surface, soil moisture losses are high and the soil tends to be droughty. This flat-ridge-top soil structure is the least productive in terms of plant growth at the fort.

I.C.2. Sloping-Hillside Soils. The sloping-hillside soils are characterized by the Clarksville series. The soil is deep loam with a high fraction (up to fifty percent) of dolomitic cherty material. Because the chert has little water-holding capacity, a sixty-inch profile of the soil can hold only between about four and seven inches of water. However, the chertiness causes the soil to be relatively firm throughout the year, and those localities where it is found are almost always accessible to machinery. Occasional rock outcroppings are to be found in the sloping-hillside soil area.

The sloping-hillside soils on the inclined land which faces to the north and east tend to be less droughty in July and August than is the case for hillsides which face south and west. This somewhat better soil water supply in summer causes the hillsides facing north and east to have better plant-matter productivity than the hillsides facing in the opposite directions. However, essentially all the sloping-hillside soils are more fertile than the flat-ridge-top soils.

Plant nutrient levels in the sloping-hillside soils are relatively low. The naturally provided fixed-nitrogen supply is estimated to be only about twenty pounds per acre per year. The phosphorus supply is about fifty pounds per acre, and potassium runs between about sixty and seventy pounds per acre. It may therefore be necessary to augment the phosphorus and potassium supplies if high yields of plant material are to be produced on sites composed of sloping-hillside soil. It will definitely be necessary to augment the fixed-nitrogen supply by about 200 to 300 pounds per acre per annum. These plant nutrient deficiencies will have to be overcome with fertilizer in the first three or four years of any Energy Plantation operations on sloping-hillside soil sites. However, if the plant-matter residues from methane production are returned to these sites, they will supply most of the fertilizer requirements in succeeding years.

As the sloping hillsides approach the creek beds, the slope of the land becomes too steep for Energy Plantation purposes. Generally speaking, land whose slope is greater than about fifteen degrees is unsuitable for Energy Plantations. The approximate boundaries between hillside land too steep for Energy Plantation operation and that which would be satisfactory are shown in Figure H-II. These boundaries are indicated by the dashed lines on the sketch map. The locations of these boundary lines were determined from geodetic survey maps of the area.

I.C.3. Bottomland Soils. The bottomland soils along the creek beds are classified in the Claiborne series. They comprise, however, only about five percent (approximately 5,000 acres) of the land surface on the fort. While they are the most fertile of the three soil types on the post, they are subject to seasonal flooding in the spring. We have excluded these soil areas, at least for the time being, from consideration for Energy Plantations because of their relatively small area and their susceptibility to flooding.

I.D. Climate. The climate at Fort Leonard Wood is typically continental--that is, summers tend to be hot and winters wet and cold. Precipitation averages between about thirty-eight and forty inches per year, although in about one year in ten it is likely to fall below thirty inches. It exceeds fifty inches with about the same frequency. Precipitation is fairly evenly spread throughout the year, but rainfall in May and June tends to be moderately above the annual monthly average. There is, however, a distinct seasonal variation in soil moisture. Precipitation in the six-month period from October to March is greater than soil water depletion from seepage, evaporation and runoff. The opposite usually holds for the April-through-September period. The result of this precipitation supply-water depletion balance is a regular tendency in three years out of four for a droughty soil condition to develop toward the end of July or in early August. This condition lasts about thirty days. In one year out of four, the droughtiness starts earlier and lasts for about sixty days. These low soil moisture levels in summertime are a major limitation to agricultural productivity in the vicinity of Fort Leonard Wood. Snow occurs in the winter, but it rarely stays on the ground longer than a few days.

Local factors cause temperatures to be slightly lower in the locale of the fort than in the region as a whole. The mean average temperature is about 57.5 degrees Fahrenheit. The absolute maximum on record for the post is 102 degrees Fahrenheit, and the lowest recorded temperature is minus eight. The mean summertime temperature is 75.5 degrees, but the temperature can fall to as low as 45 degrees on occasion. The mean wintertime temperature is 34.7 degrees, but it has risen to about 72 degrees Fahrenheit on occasion. Cold waves sometimes occur, but they seldom last for more than a few days. In the summertime, temperatures approach the recorded maximum temperature in about two years in every ten. However, these extreme hot waves rarely last for more than four days.

Freezing temperatures occur every winter. The probability of the occurrence of such low temperatures is summarized in Table H-I. The indication from the data in this table is that there are about 5.5 months of frost-free weather every year.

Taken as a whole, these various climate considerations suggest that the most favorable times in the year for substantial plant growth are from about the end of April into July, and for a few weeks in September and early October. Cool-season perennial grasses under these conditions are unlikely to afford more than two crops a year on a regular basis. Warm-season perennial grasses are not likely to be suitable because they will not make much progress before the onset of low soil moisture conditions nearly every summer. The preferred plant species will therefore be deciduous trees grown in dense plantings on harvest cycles of two to four years.

I.E. Vegetation. The prevailing natural tree species at the fort are various hardwoods, particularly oak and hickory. Perhaps because the region is at the northern boundary of shortleaf pine region, this species is found only on a few of the south and west-facing hillsides. Data on tree species found in commercial forests in the vicinity of the post are summarized in Table H-II.

On the fort itself, vegetation types can be described by the rough physiographic classifications of the terrain. Vegetation found on ridgetops is chiefly an association of post oak and blackjack oak with some black oak growing where soil fertility and soil moisture are adequate. Vegetation on the north and east facing slopes is primarily black oak and hickory with other species of oak present. Hickory is less abundant and some shortleaf pine is present on the south and west-facing slopes. The vegetation on the bottomlands is a mixture of hardwoods--hickory, elm, red and silver maples, tulip poplar, sycamore and others. The quality of the timber on the fort is not especially good. Because

TABLE H-I

THE PROBABILITY OF FREEZING TEMPERATURES IN THE SPRING AND FALL IN THE VICINITY OF FORT LEONARD WOOD

PROBABILITY	DATE OF OCCURRENCE FOR GIVEN PROBABILITY AND TEMPERATURE				
	32°F	28°F	24°F	20°F	16°F
Spring:					
5 years in 10 later than	April 24	April 9	March 30	March 19	March 6
2 years in 10 later than	May 3	April 16	April 8	March 31	March 23
1 year in 10 later than	May 8	April 20	April 13	April 7	March 31
Fall:					
5 years in 10 earlier than	October 13	October 26	November 3	November 9	November 20
2 years in 10 earlier than	October 4	October 19	October 28	November 1	November 8
1 year in 10 earlier than	September 30	October 15	October 25	October 28	November 2

timbering has not been allowed until recently, there are some fairly large trees.

The areas comprised of abandoned farms acquired in this last decade, and more especially land cleared and now being used by the army, support growth of a mixture of prairie grasses. It is believed that at sometime in the past, flat-ridge-top areas were part of the tall grass prairie.

I.F. Pest Problems and Other Hazards. No outstanding pest problems are reported for the area in which Fort Leonard Wood is situated. This happy circumstance may be due primarily to the fact that managed vegetation is not produced there, because there is evidence that various pests are present. For example, typical pine pests found include tip moth, bark beetles, root rot and deer. Among the oaks, pests noted are oak wilt, oak leaf beetle, tent caterpillars, and small rodents. Young white pine plantations were attacked by deer and bark beetles, but competition from native tree species caused much more damage. One potential problem to which local people seem to attach little significance is the large number of grasshoppers observed in some crop fields and overgrazed pastures.

Young trees, particularly pines, showed evidence of sun scald damage. Frost heaving is reported to be a problem for young trees planted on the ridge tops. Ice storm damage was observed in the older trees.

These various possible pest problems suggest that a mixture of species should be planted on any Energy Plantation established on or near the fort. Sun scald is not likely to be a problem because conifers are not a species likely to be grown. Ice storms are unlikely to be a problem because production of mature trees is not contemplated. Frost heaving will not be serious because ridge-top

TABLE H-II

TREE SPECIES IN COMMERCIAL FORESTS IN THE VICINITY OF FORT LEONARD WOOD

FOREST TYPE	APPROXIMATE ACREAGE	APPROXIMATE PERCENTAGE OF TOTAL ACREAGE
Pine	6,200	7
Oak - Pine	100	-
Oak - Hickory	69,300	80
Post and Blackjack Oak	7,300	8
Bottomland Hardwoods	3,900	4
Totals	86,800	100

Source: Private communication from Neal Morrison, Assistant Ranger, Rolla Ranger District, Missouri.

land is unlikely to be used and in any event accumulating leaf litter will reduce the effect of freeze-thaw cycles.

Losses due to fire are typically low in the naturally forested areas on and around the fort. The incidence of fire on the fort itself is, however, slightly higher than in regions outside it. Fire control appears to be effective in the area, with the result that when fires break out, they are quickly extinguished.

I.G. Land Availability at the Fort. The areas on the fort which clearly could not be considered for Energy Plantations because of their present uses are summarized in Figure H-III. These areas include firing ranges, the impact zone for mortar fire, the landing strip, and the built-up area occupied by the main post.

In Figure H-IV, Figure H-II (primarily topographical and soil quality information) and Figure H-III (primarily land uses) have been superimposed, thereby identifying three possible Energy Plantation sites. The sites are designated as areas I, II, and III. The three areas taken together cover about twenty-five square miles. They are all on hillside land having slopes of fifteen degrees or less. If solid fuel were produced on them, sustained production is likely to be about sufficient to meet seventy percent of the present energy requirements at the fort. If the plant material produced were to be converted to fuel gas, the resulting volume probably would be sufficient for about half the total present fuel consumption at Fort Leonard Wood.

Area I, located southwest of Forney Army Airfield, covers between seventeen and eighteen square miles. It is defined on the north and west by steeply sloping ground and the reservation boundary. The southern boundary is Roubidoux

Creek and ranges eighteen, fifty-two and fifty-three. Available land is limited on the east by the change to flat-ridge-top soil and by Forney Army Airfield.

Area II is bounded on the east and south by the reservation boundary and steeply sloping ground. Purposely, however, no western and northern boundaries have been defined. It is proposed that land used for Energy Plantations have, if possible, multiple uses. For instance, plantations might serve also to dampen noise of range fire and maneuvers from civilian communities located directly outside the base. Here such a possibility exists. None of the ranges in restricted area R-4501-B in the southeast portion of the fort is used for firing explosive shells. In addition, all of these ranges, except one which is used for firing M60 machine guns and AK47 automatic assault rifles, are small-arms ranges. Incendiary shell and tracer fire is probably quite limited. The down-range areas of these ranges could therefore serve both as firing ranges and as Energy Plantations. Schedules could be managed so that no Energy Plantation personnel are on the range during firing. But this dovetailing can probably be achieved without hindering operation of either the range or the plantation. Thus, the Energy Plantation could be built within a kilometer or so of the rear of the target areas, thereby making between four and five square miles available for plant-matter production.

Area III is bounded on the north by Range 50 and on the south by the reservation boundary. The western boundary is defined by Roubidoux Creek and steeply sloping land. The eastern edge is defined by the reservation boundary and a change to flat-ridge-top soil. This area covers approximately four square miles.

It has been proposed that consideration be given to establishing Energy Plantations as a buffer zone for noise and privacy control around the military reservation. This buffer could, in principle, be just inside the perimeter of the

reservation, or just outside it. In the case of Fort Leonard Wood, a strip about one thousand yards wide all around the perimeter could supply all the fuels requirement for the fixed installations at the fort if they were fired with solid fuel. A strip about thirteen hundred yards wide would be adequate if fuel gas is to be used for meeting these fuel needs.

Reference to Figure H-IV shows that because of the steeply sloping land at several locations on the perimeter of the fort, and because firing ranges and other restricted areas abut the perimeter, it does not appear to be possible to establish an Energy Plantation strip around the fort immediately inside its perimeter. The possibility for such a strip just outside the fort does not appear to be any more feasible. Much of the eastern and western boundaries of the reservation is steeply sloping land on the outside of the perimeter. Only parts of the northern boundary and the southwest corner appear to be suitable for Energy Plantation use immediately outside the perimeter of the fort.

MAPS

FORT LEONARD WOOD

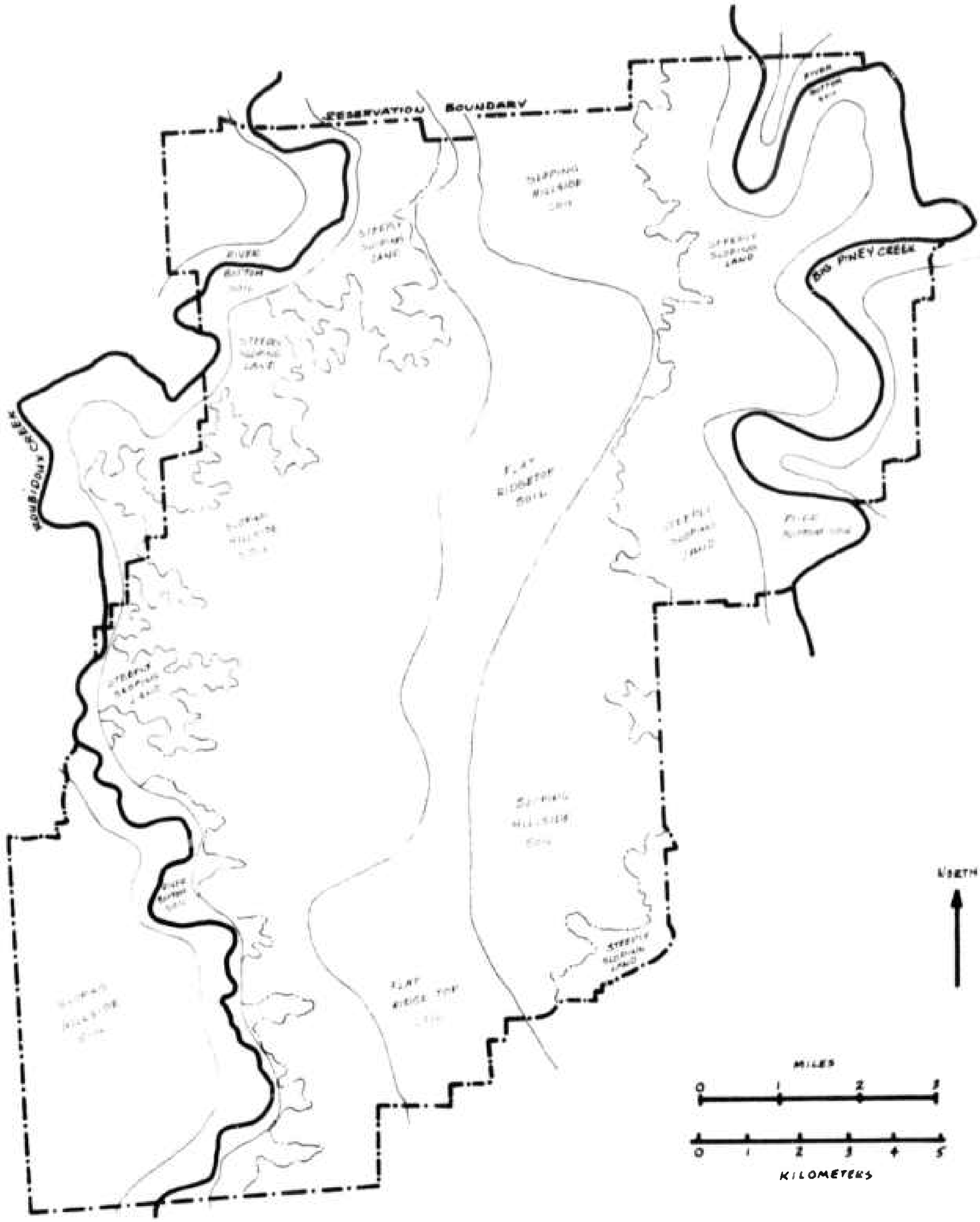

RESERVATION BOUNDARY
ROUBIDOUX CREEK
BIG PINEY CREEK
RIVER BOTTOM SOIL
STEEPLY SLOPING LAND
FLAT RIDGETOP SOIL
NORTH
MILES
0
1
2
3
0
1
2
3
4
5
KILOMETERS

FIGURE H-II

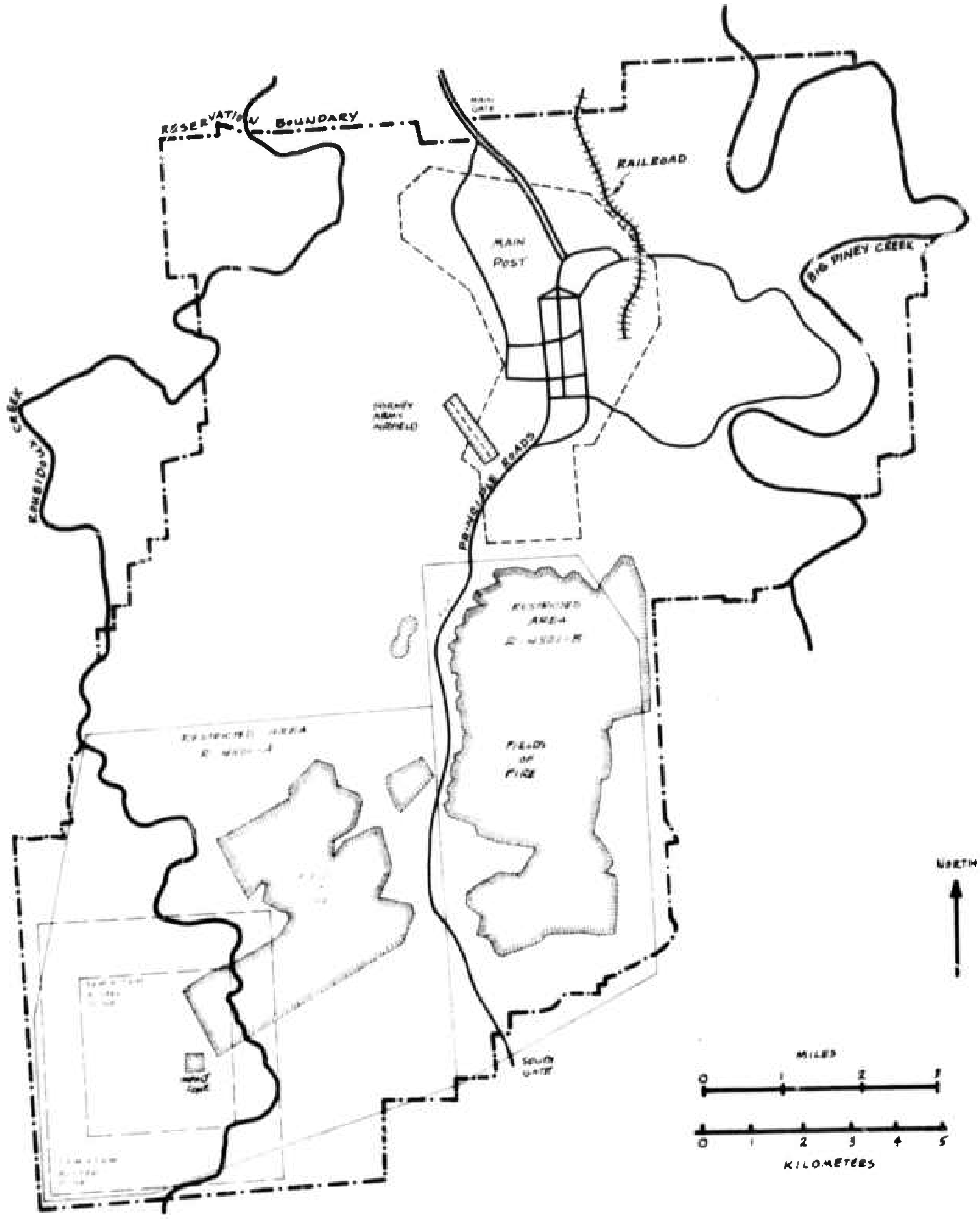


FIGURE H-III

Preceding page blank

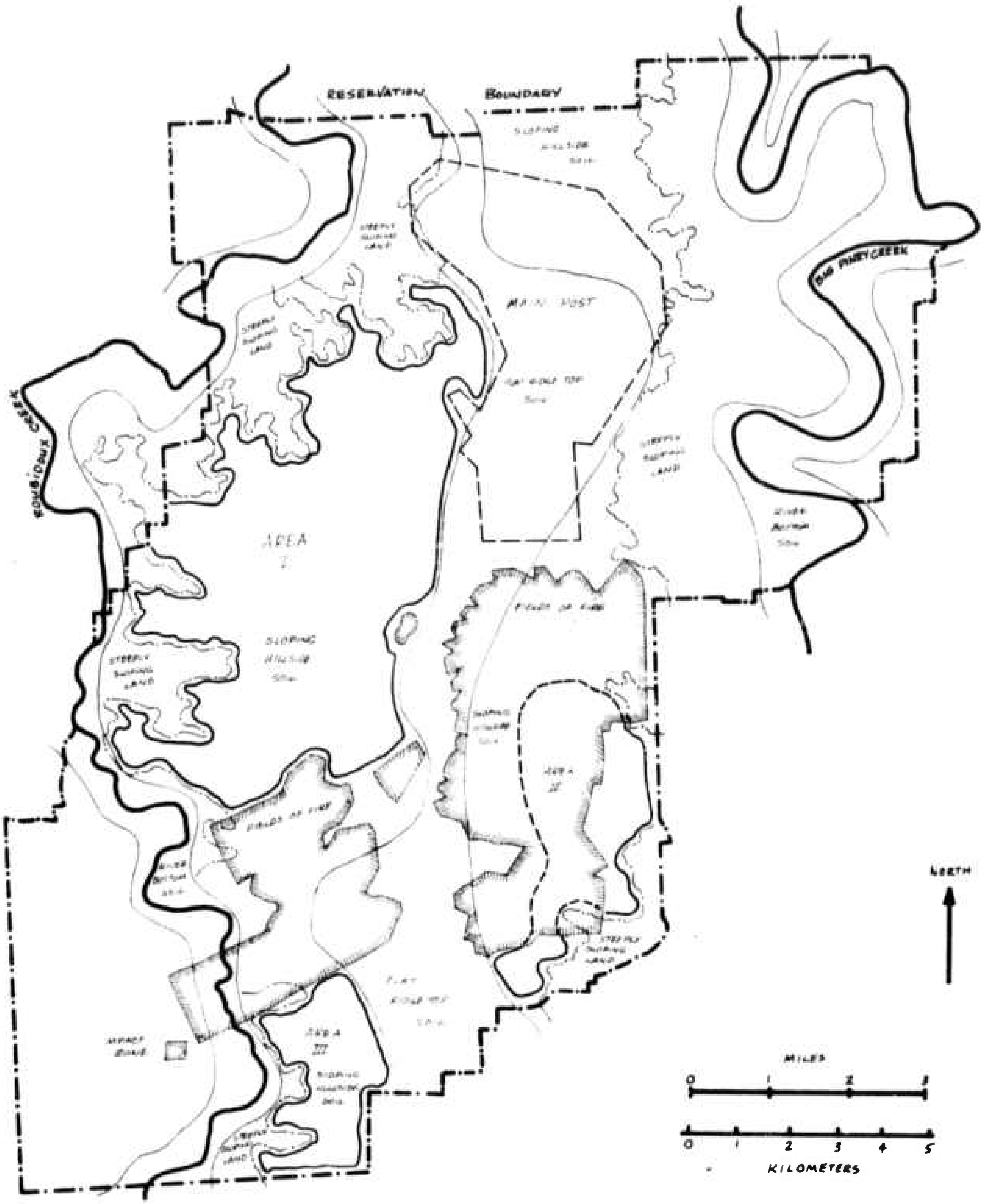


FIGURE H-IV

Preceding page blank

II. FORT BENNING

II.A. Introduction. Dr. Jean F. Henry and Charles W. Vail, members of InterTechnology's staff, visited the locality of Fort Benning on 13 August 1974. During that day, they met with, and toured the area with:

Claud (Dick) Collier - County Extension Agent for Muscogee County, Georgia, and

William C. Player - Conservationist for Muscogee and Chattahoochee Counties, Georgia, U.S. Soil Conservation Service.

Most of Fort Benning is located east of the Chattahoochee River in central Georgia on the western edge of the state, just south and east of Columbus. A small part of the base is across the river in Alabama. In Georgia, the base includes parts of Muscogee and Chattahoochee counties. In Alabama, it includes part of Russell County.

II.B. Topography. The topography at the fort is rolling to moderately hilly uplands dissected by several creeks. More precisely, the terrain consists of a series of broad and narrow ridges generally tending north and south, but there are also some irregular knobs, peaks and hogback ridges. In their upper reaches, stream valleys are narrow, but further downstream they broaden out with the streams following widely meandering courses. All streams flow to the south or west into the Chattahoochee River.

The fort is generally situated astride the interface between the Piedmont Geologic Province and the Coastal Plain Province. The interface is a wide zone, commonly referred to as the Fall Line, which runs from the southwest to the northeast. The Piedmont Geologic Province is northwest of the Fall

Line, and the Coastal Plain Province is to the southeast of it. The interfacial zone in which the Fall Line lies is part of the range of sand hills which extends into Alabama on the southwest and across Georgia into the Carolinas on the northeast. The soil in the interfacial zone is a mixture of Piedmont and Coastal Plain characteristics. However, on the fort itself, Coastal Plain characteristics predominate, although immediately outside the fort in the sector extending approximately from the southwest around to the northeast, the Piedmont characteristics are more prevalent.

This intermediary zone between two distinct geologic provinces is characterized by relatively small and numerous areas displaying a homogeneous mixture of the soils of both Piedmont and Coastal Plain. Beyond the broad topographic description of stream margin and river bottom, there are no other readily identifiable features except for the broad soil types present. Since the best available data was a 1922 soil survey of Chattahoochie County, this description of the area has been stated in terms of broad soil types.

II.C. Soils. On the fort, five soils types stand out from the generally unconsolidated, essentially horizontal beds of sands, silts and clays found there. In those locations where Coastal Plain character is dominant, the soils are Red Yellow Podzolic soils group. The deep sand in the Fall Line are described as Regosols. The soils in and adjacent to the stream beds are of two major silty alluvial types. Broadly they are described as Humic Gley soils from the Bibb and Ochlocknee series, respectively.

The soil types found in the locality of Fort Benning have been classified by the Soil Conservation Service into "Woodland Suitability Groups" according to their drainage, slope, susceptibility to erosion and potential for timber production and pasture. Using these classifications and observations made by Collier and Player during the tour in the Fort Benning area, estimates have been made of the suitability of each of the major soil systems at Fort Benning for Energy Plantation purposes. These estimates are the subject of the following five subtitled paragraphs.

II.C.1. Deep Sandy Soils. Numerous fairly extensive areas of these sands are spread throughout Fort Benning. These areas account for more than half the total area in the fort. They are interspersed with various other soil systems.

The deep sands are classified as members of the Eustis and Troup series in the Regosol group. They are generally found on inclines having slopes between about two and fifteen percent, and are well to excessively drained because they exhibit rapid internal drainage. Erosion due to water is greater than that due to wind, but erosion is not a serious problem in areas supporting vegetation. The deep sand areas are moderately accessible to equipment, least accessibility occurring during the more droughty periods, which most often occur in September and October.

Natural mortality for conifer seedlings in the deep sand areas is caused primarily by the droughty periods but overall is only moderate. Productivity in these areas is also only moderate, their site indices for slash and loblolly pine being in the seventy to eighty range. The deep sands are extremely acid.

The deep sand areas are the least productive on the fort. However, in the opinions of Collier and Player, amending them with a humus layer as shallow as one or two inches could make them as productive as the sandy loams. Such a humus layer, besides adding organic matter to the soil, would cause better retention of moisture and fertilizers. They suggested planting a sod-forming grass as a good means for establishing the humus layer. In their view, coastal bermudagrass and suwanee bermudagrass would be good candidates for this purpose because they can tolerate the low soil pH and periods of droughtiness. It is estimated that it would take five or six years to establish the humus layer, and in its absence the deep sand soils are not attractive sites for

deciduous tree species grown in dense plantings with repeated harvests at intervals of two to four years.

Collier and Player also mentioned that deep sand soil areas in an Energy Plantation would have to be managed in such a way that periods when the soil is bare are minimized. Bare ground is not only far more subject to erosion, but in summer it gets hotter and drier than it does when supporting vegetation. Under these conditions mortality of young plants could be a problem.

II.C.2. Sandy Loam Soils. These soils account for about a quarter of the area in Fort Benning. They are one of the soils characteristic of the Coastal Plain Province. They occur in patches of ten to twenty acres or more throughout the base. They are generally found on uplands and terraces where slopes range from about zero to fifteen percent.

The sandy loam soils belong to several series within the Red Yellow Podzolic soils group, of which the more prevalent on Fort Benning are the Gilead, Hoffman and Lakeland series. They are generally well drained and not subject to erosion. They impose at the most only slight limitation to field machinery operation.

Natural mortality for pine seedlings in this soil is low. Their productivity is relatively high, their site indices for slash and loblolly being between eighty and ninety. They are therefore considerably more productive than the deep sands in the Fall Line. They are quite acid. They appear well suited to coastal bermudagrass culture and are probably also satisfactory for suwanee bermudagrass and possibly also for napiergrass. They may be suited to culture of red maple and selected poplar hybrids in dense plantings with repeated harvesting at two to four-year intervals. Overall, therefore, these soils are rated superior from an Energy Plantation point of view to the more frequently encountered deep sand soils at Fort Benning.

II.C.3. Silty Loam Soils. These soils are the third most frequently found soil type at Fort Benning. Collier and Player estimate that they cover at least 15,000 acres in the better drained areas of the bottomlands adjacent to the stream courses at the fort. In many locations, they are subject to occasional flooding, but generally they are well drained. The terrain in which they are located is flat to gently inclined with slopes rarely exceeding two percent. They offer few impediments to field machinery operation. They are not subject to erosion. Like the two more prevalent soil systems previously described, these soils are also relatively acid.

The silty loam soils are the most productive on Fort Benning. Their slash and loblolly site indices are ninety or better. Moreover, their indices for sycamore and eastern cottonwood are also high, being ninety and 110, respectively. They are therefore rated as eminently suitable from the Energy Plantation point of view. It is likely that sustained annual yields of ten air-dry tons or more per acre can be produced from sycamore, cottonwood and other deciduous tree species which thrive on relatively moist soils.

II.C.4. Poorly Drained Silty Soils. These soils are also found in the bottomlands along streams at the fort. However, they are poorly drained, regularly flooded, and often hold standing water in shallow depressions in their surface. They are relatively inaccessible to conventional field machinery. If these soils were drained, they might be as productive as the silty loam soils. Dams built by beavers, a protected species at the fort, are a factor contributing to the poor drainage. These soils are not good candidates for Energy Plantation purposes in the foreseeable future.

II.C.5. Clay Soils. These soils, while not widely distributed on the fort, are quite prevalent in the territory in Georgia immediately to the south and southeast of the fort. They are one of the soil types frequently

found in the Coastal Plain Province. They are not especially productive (their slash and loblolly site indices are about eighty), and they suffer from a strong shrink-swell characteristic because they have poor internal drainage. Moreover, to the south and southeast of the fort, the terrain in which they are located is relatively sharply hilly. These soils, and the topography where they are located near Fort Benning, are not promising for Energy Plantation purposes.

II.D. Climate. The climate in the vicinity of Fort Benning is characteristic of the humid southeast. While it is usually controlled by maritime effects emanating from the Gulf and the Atlantic Ocean, it occasionally, particularly in winter, comes under the influence of continental weather systems flowing southwards across the Midwest from Canada.

The annual mean temperature is about 64° Fahrenheit, and it varies from year to year between about 63° and 69° Fahrenheit. The coldest month in the year is usually January, for which the lowest average monthly temperature on record is about 36° Fahrenheit. July is the warmest month with monthly average temperatures ranging from about 78° to 85° Fahrenheit. However, maximum daily temperatures are in the low nineties on most days in June, July and August.

Frosts occur in wintertime, and temperatures often drop to as low as 20° Fahrenheit on some days in January. Temperatures will remain below freezing all day for a day or two in January in about one year out of every four or five years.

The growing season extends over about 240 days a year.

found in the Coastal Plain Province. They are not especially productive (their slash and loblolly site indices are about eighty), and they suffer from a strong shrink-swell characteristic because they have poor internal drainage. Moreover, to the south and southeast of the fort, the terrain in which they are located is relatively sharply hilly. These soils, and the topography where they are located near Fort Benning, are not promising for Energy Plantation purposes.

II.D. Climate. The climate in the vicinity of Fort Benning is characteristic of the humid southeast. While it is usually controlled by maritime effects emanating from the Gulf and the Atlantic Ocean, it occasionally, particularly in winter, comes under the influence of continental weather systems flowing southwards across the Midwest from Canada.

The annual mean temperature is about 64° Fahrenheit, and it varies from year to year between about 63° and 69° Fahrenheit. The coldest month in the year is usually January, for which the lowest average monthly temperature on record is about 36° Fahrenheit. July is the warmest month with monthly average temperatures ranging from about 78° to 85° Fahrenheit. However, maximum daily temperatures are in the low nineties on most days in June, July and August.

Frosts occur in wintertime, and temperatures often drop to as low as 20° Fahrenheit on some days in January. Temperatures will remain below freezing all day for a day or two in January in about one year out of every four or five years.

The growing season extends over about 240 days a year.

Rainfall averages about forty-nine inches per year, although within living memory it has been as low as thirty inches (1954) and as high as seventy-three inches (1929). The rainiest months are March and July with about six inches of rainfall each. September and October are the driest months when rainfall may be as little as about two inches per month. During the other eight months, rainfall is evenly distributed at about four inches per month. Local thundershowers account for a substantial part of the rainfall in the summertime. Snow falls only very rarely at Fort Benning and, in any event, even more rarely remains on the ground for more than a few hours.

In every month of the year except January, the actual sunshine is at least fifty percent of the theoretical maximum possible. In January it averages only forty-eight percent of the theoretical, but for the year as a whole, it averages about sixty-one percent of the theoretical maximum.

The climate in the vicinity of Fort Benning is therefore conducive to high rates of plant-matter production. However, soil moisture retention in the sandier soils is relatively poor although it is much better in the sandy loams and quite good in the silty loam soils. In other words, plant-matter production is limited more by the moisture retention quality of the soil locally than it is by the climate generally in the vicinity of Fort Benning. Consequently, as previously noted in the discussion of soil types in and around the fort, soil productivity varies widely over short distances as the soil changes between less sandy and more sandy types.

II.E. Soil Fertilization. Naturally available fertilizer levels are also relatively low in several soil types on and in the vicinity of Fort Benning. Naturally provided fixed nitrogen averages only about twenty pounds (as elemental nitrogen) per acre per year in the region generally. Phosphorus (as P_2O_5) from natural sources ranges between about twenty and forty-five pounds

per acre per year, and potassium (as K_2O) is generally less than fifty pounds per acre per year. Artificial fertilization is unlikely to help much in the deep sandy soils because of the high rate at which it is leached out by the poor water-retaining character of these soils. However, fertilizer application will be considerably more effective in the sandy loam and silty loam soils.

II.F. Pest Problems and other Hazards. Pest problems are very nebulous. As previously indicated, beavers pose a problem for the drainage in certain areas. Deer populations are large and anything tender or green would be attractive to them. Grasshoppers are present and a problem for some crops. Pine is attacked by various fungi as well as black turpentine beetles, Ips beetles and southern pine beetles. Coastal bermudagrass is attacked by spittle bugs and army worms and invaded by bahiagrass, although these pests can be controlled. No known pests occur in epidemic populations in hardwoods because there is little or no large-scale production of hardwood in the area. It is concluded that the possible effect of pests is unknown at present.

Forest fires are a considerable problem throughout the area. While Georgia has the fewest number of acres lost to fires yearly among the states, the state also has the highest number of fires reported yearly. Fires in juvenile deciduous plantations are likely, however, to be fewer and less severe than in conifer stands.

II.G. Suitable Land at the Fort. This analysis of soil and climate leads to the following tentative conclusions with respect to Energy Plantation operation in and around Fort Benning:

- the sandy loam soils which account for about a quarter of the area in Fort Benning (roughly forty to fifty thousand acres) appear to be suitable for intense production of coastal bermudagrass and other

grasses which tolerate rather acid soils and occasional droughtiness--selected hybrid poplars and red maple may also be productive in these soils--fertilization will be required, but ash and spent biological digester sludge produced respectively from burning solid fuel produced in Energy Plantations and from methane production from the product of Energy Plantations will contribute substantially to the fertilizer requirement--the productivity of these soils will increase for Energy Plantation purposes as organic litter accumulates in the soil as a result of Energy Plantation operation, and could easily reach ten air-dry tons of plant matter per acre per year--the terrain where these soils are located is generally suitable for field machinery;

- the silty loam soils, of which there are about 15,000 acres on the fort, appear to be eminently suited to Energy Plantation production of eastern cottonwood, sycamore and other deciduous species adapted to moist soils--annual plant-matter yields are expected to be ten air-dry tons per acre or better with Energy Plantation cultural practices and fertilization with recycled ash and spent biological digester sludge;

- none of the other soil types at Fort Benning is considered particularly promising for Energy Plantations; and

- a strip of land about 1,500 yards wide around the perimeter of the fort devoted to Energy Plantation operation will be adequate to supply all the energy requirements of the fixed installations at Fort Benning if they are all fired with gaseous fuel produced from plant material grown in the plantations--a narrower strip will be needed if part of the requirement can be met with solid fuel--but the strip will have to be proportionately wider if part of the periphery cannot be used because of the obstructions such as buildings or the presence of particularly unproductive land.